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Background Document for the Ground-Water Screening Procedure to Support 40 CFR Part 268 - Land Disposal Restrictions (Includes Appendixes A-G)

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The Background Document for the Ground Water Screening Procedure provides information on the model developed by the Office of Solid Waste to determine maximum acceptable concentrations for hazardous constituents in extracts of wastes. The ground-water screening procedure involves a back calculation from a point of potential exposure at a distance downgradient from a land disposal unit to a point of release from the unit using a fate and transport model.

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BACKGROUND DOCUMENT

GROUND WATER SCREENING PROCEDURE

OFFICE OF SOLID WASTE
U.S. ENVIRONMENTAL PROTECTION AGENCY

JAN 1986

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Appendix A —

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BACKGROUND DOCUMENT

GROUND WATER SCREENING PROCEDURE

OFFICE OF SOLID WASTE

U.S. ENVIRONMENTAL PROTECTION AGENCY

JAN 1986

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1 INTRODUCTION

The Resource Conservation and Recovery Act (RCRA) as ammended in 1984 requires EPA to promulgate regulations which restrict land disposal of hazardous wastes unless it is determined by EPA that a prohibition is not required to protect human health and the environment The restrictions apply for as long as the waste remains hazardous.

In promulgating such regulations, Congress has directed EPA to consider:

A. The long-term uncertainties associated with land disposal;

B. The goal of managing hazardous wastes in an appropriate manner; and

C. The persistence, toxicity, mobility, and propensity of hazardous wastes and their constituents to bioaccumulate.

EPA's Office of Solid Waste (OSW) reviewed a number of approaches which could serve to evaluate the need to ban or further restrict hazardous wastes from land disposal. The general approaches examined included decision criteria schemes, numerical schemes, modeling schemes, and combinations of all three. The approach presented in this paper, developed by OSW represents one option considered by EPA. It combines a mathematical model for solute transport with health based concentration limits and a leach test.

EPA's approach provides a systematic, consistent, and non-capricious method for determining the need to restrict hazardous wastes from land disposal. EPA's approach is designed to establish acceptable concentrations for specific chemical constituents in waste extracts by working backward from a point of potential human exposure (through air, groundwater, and surface water) to the land disposal unit. Health assessment levels for each constituent will be appropriately partitioned into the three media.

This paper presents the groundwater screening component of EPA's approach. It is important note that in this approach decisions on restricting land disposal of hazardous wastes will be made on a national basis. The RCRA reauthorization legislation establishes a petition process for consideration of site specific factors.

The groundwater screening procedure presented in this paper involves application of an analytic solute transport equation in conjunction with values for hydrogeologic parameters, such as groundwater velocity, soil porosity, net infiltration, etc., that are applied in a Monte Carlo routine to derrive a distribution of outputs.

The EPA approach is based on the following general assumptions:

(1) Decisions to restrict the land disposal of hazardous wastes will be made on a national basis.

(2) Restrictions decisions will be linked to health assessment levels, i.e., the reference dose.

(3) The procedure developed by EPA to restrict the land disposal of hazardous wastes are to accomodate the variations in environmental settings, and the uncertainties in specific chemical properties.

The scenario to be applied in conjunction with the ground water screening procedure is a land disposal unit with a fixed point of measurement established at distance x_1 down gradient. Figure 1 illustrates a cross section and a plan view of this system.

The groundwater screening procedure can be described qualitatively as follows.

(1) A waste will be determined accepatble for land disposal if specific chemical constituents are projected to migrate to the fixed measurement point at concentrations equal to or less than the reference dose for those chemicals.

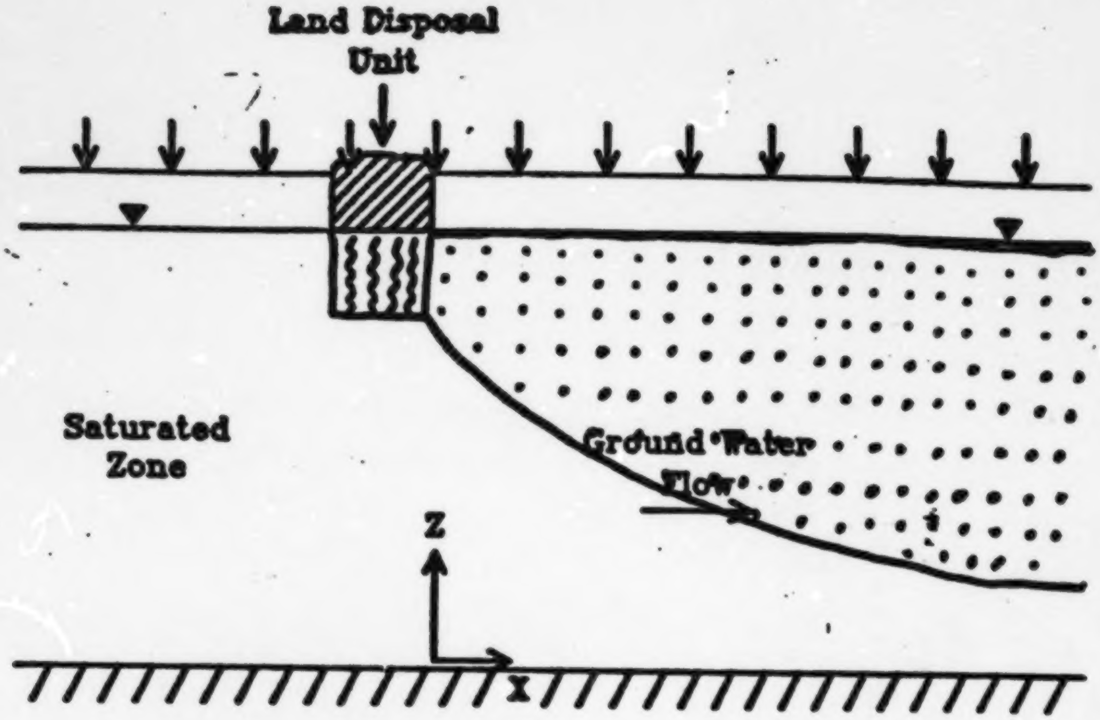
(2) If constituents in hazardous wastes migrate to the fixed measurement point at concentrations above the reference dose, then the waste will be restricted from land disposal.

(4) Land disposal will be permitted, however, if it is possible to pretreat the waste such that the constituent concentration in the groundwater at the measurement point no longer exceeds the reference dose.

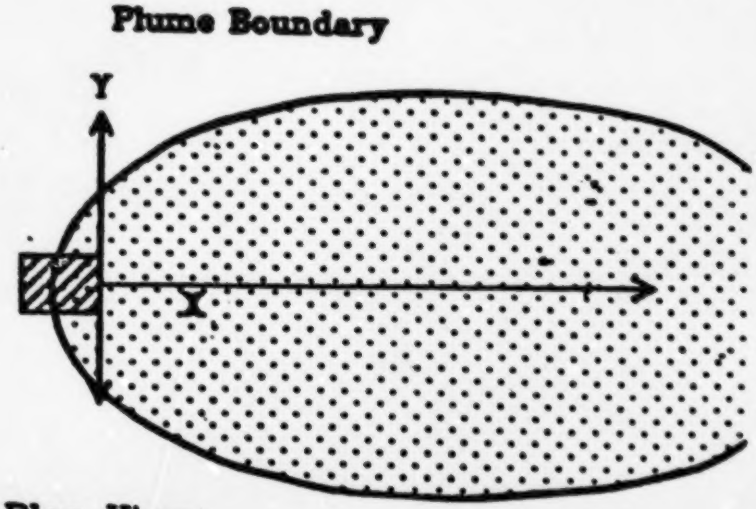
In order to apply the groundwater screening procedure, one must be able to measure, estimate, or predict:

(1) leachate concentrations of specific chemical constituents from a waste; and

(2) the migration of the chemical constituents in the leachate to the measurement point.


Land Disposal Unit
Saturated Zone
Ground Water Flow
Z
X

Cross Section


Plume Boundary
Y
X

Plan View

Figure 1

2 MATHEMATICAL MODEL

A mathematical model is used to provide an instrument for computing concentration distributions in the generic groundwater system (depicted in Figure 1). The model is explained below in general terms, and sample calculations are provided. A detailed explanation of the mathematical techniques employed in the model is presented in Appendix A at the end of the paper. The mathematical techniques employed in the model are, however, based upon analytical solution procedures well established in the scientific literature.

The ground water back-calculation model properly accounts for most of the major physical and chemical processes known to influence movement and transformations of chemicals in simple, homogeneous and isotropic porous media under steady flow conditions (constant velocity). The important mechanisms considered include advection, hydrodynamic dispersion in the longitudinal, lateral and vertical dimensions, adsorption, and chemical degradation. The model assumes first-order chemical reactions, and linear equilibrium sorption isotherms.

The three-dimensional solute transport equation upon which the ground water screening model is based is presented below as Equation (1), written in the form (Bear, 1979):

$$D_{xx}\frac{\partial^2 c}{\partial x^2} + D_{yy}\frac{\partial^2 c}{\partial y^2} + D_{zz}\frac{\partial^2 c}{\partial z^2} - \frac{V}{R_f}\frac{\partial c}{\partial x} = \frac{\partial c}{\partial t} + c + Ic \qquad (1)$$

where:

x, y, z = spatial coordinates in the longitudinal, lateral and vertical directions, respectively, (m)

c = dissolved concentration of chemical, (g/ml)

D_{xx}, D_{yy}, D_{zz} = retarded dispersion coefficients in the x, y and z directions, respectively, (m^2/yr)

V = groundwater seepage velocity, assumed to be in the x-direction, (m/yr)

R_f = retardation factor, (dimensionless)

t = elapsed time, (yr)

= effective first-order decay constant, (yr^{-1})

θ = volumetric water content of the porous medium, (cm^3/cm^3)

I = rate of ground water recharge from precipitation (yr^{-1})

The retardation factor, R, and the effective decay constant, λ, are defined as follows:

$$R_f = 1 + \frac{P_b K_d}{\theta} \tag{2}$$

and,

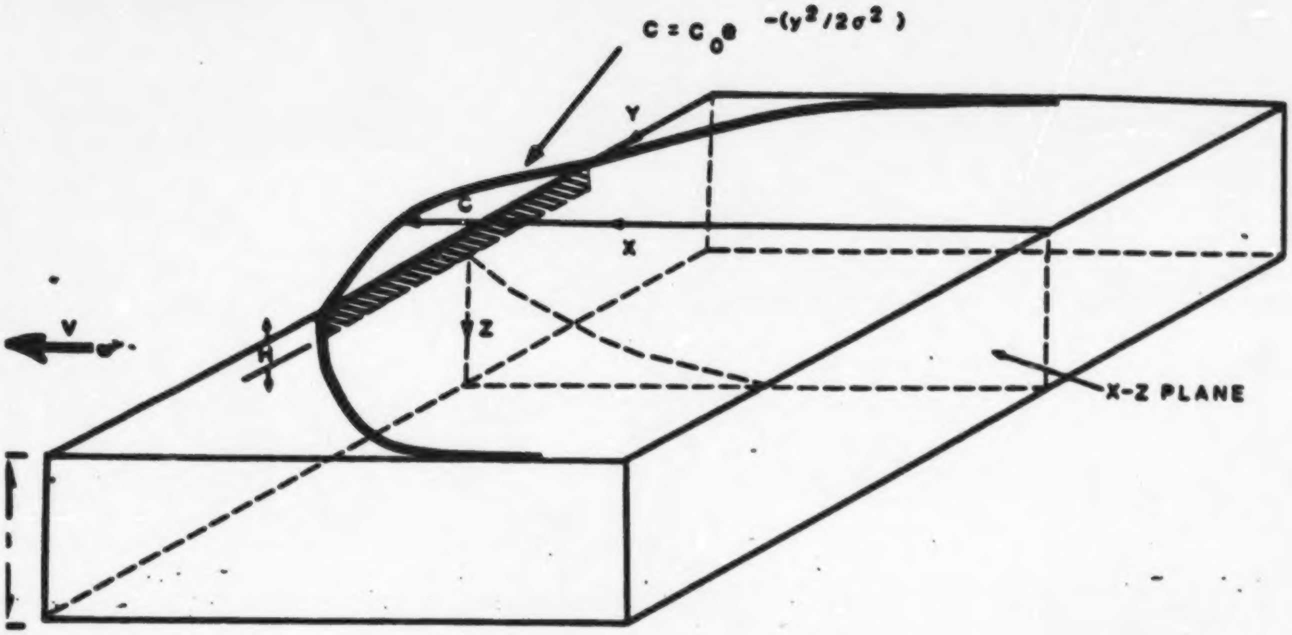
$$\lambda = \frac{\lambda_1 \theta + \lambda_2 \, {}_b K_d}{\theta + {}_b K_d} \tag{3}$$

where:

ρ_b = bulk density of the porous medium, (g/cm3)
K_d = distribution coefficient, (cm3/g)
θ = volumetric water content, (cm3/cm3)
λ_1 = decay constant for dissolved phase, (yr^{-1})
λ_2 = decay constant for sorbed phase, (yr^{-1})

A schematic description of the three-dimensional region considered is presented in Figure 2. The region is regarded as semi-infinite in the x-direction ($0 \leq x < \infty$), infinite in the y-direction ($-\infty < y < \infty$), and finite in the z-direction ($0 \leq z \leq B$). Initially, the aquifer is assumed to be free of contamination

The solution treats the source concentration (i.e., the contaminant concentration in the leachate directly below the land disposal unit) as a Gaussian distribution in the lateral direction (along the y-axis corresponding to the leading, down gradient edge of the unit), and a uniform distribution over the vertical mixing or penetration depth, H. The maximum dissolved concentration of the contaminant, c_o, occurs at the center of the Gaussian distribution (i.e., at $y = 0$; under the midpoint of the disposal unit). The Gaussian distribution of the contaminant concentration is then defined by its standard deviation, σ, as illustrated in Figure 2. The standard deviation of the distribution, σ, is measured in terms of distance (meters), and is related but not equal to the width of the disposal unit.


$C = C_0 e^{-(y^2/2\sigma^2)}$
Y
C
X
V
H
Z
X-Z PLANE

PERSPECTIVE PLOT

FIGURE: 2 Schematic Description of Three-Dimensional Region For The Analytical Solution.

Based on the stated assumptions, the initial and boundary conditions employed may be written as follows:

$$c(x, y, z, 0) = 0 \qquad (4)$$

$$c(0, y, z, t) = c_o e^{-y^2/2\sigma^2} \qquad (5)$$

$$c(x, \infty, z, t) = 0 \qquad (6)$$

$$c(x, -\infty, z, t) = 0 \qquad (7)$$

$$c(\infty, y, z, t) = 0 \qquad (8)$$

$$\frac{\partial c}{\partial z}(x, y, 0, t) = 0 \qquad (9)$$

$$\frac{\partial c}{\partial z}(x, y, B, t) = 0 \qquad (10)$$

where B is the aquifer thickness.

The solution of equation (1) subjected to equations (4)-(10) is derived in Appendix A. This three-dimensional analytical solution can be written in a simple functional form as follows:

$$c_p(x, y, z, t) = \frac{H}{B} c_f(x, y, t) + \Delta c_p(x, y, z, t) \qquad (11)$$

where H/B is the penetration ratio and c_f (x, y, t) and Δc_p (x, y, z, t) are functions defined in Appendix A.

Note that the function c_f (x, y, t) turns out to be identical to the two-dimensional analytical solution of a corresponding case where full penetration of the source (or complete vertical mixing) over the entire aquifer thickness is assumed. According to equation (11), the solution for the general partial penetration case, c_p (x, y, z, t), consists of two terms. The first term is the product of the penetration ratio and the solution of the corresponding full-penetration case. It may be interpreted as the concentration that would be predicted if vertical spreading of the contaminant plume is not allowed. The second term, $c_p(x, y, z, t)$, is a correction term necessary to allow for the partial penetration effect which leads to vertical spreading or vertical dispersion. Vertical dispersion will cause the contaminant plume to grow in the vertical direction with increasing longitudinal distance from the source. The vertical extent of the plume is, however, limited by the available aquifer thickness.

3 GENERAL DIMENSIONLESS RELATIONSHIPS

To allow simple use of the analytical model, dimensionless relationships are introduced. First, equation (11) is rewritten as

$$c_{pD} = \frac{H}{B} c_{fD} + \Delta c_{pD} \qquad (12)$$

where c_{pD}, c_{fD}, and Δc_{pD} are dimensionless functions obtained by normalizing c_p, c_f and Δc_p with respect to the maximum source concentration, c_o .

Second, another dimensionless function, referred to as a dilution factor for partial penetration, ζ, is introduced as

$$\zeta = \frac{c_{pD}}{c_{fD}} = \frac{c_p}{c_f} \qquad (13)$$

Thus it follows that is given by

$$\zeta = \frac{H}{B} c_{fD} + c_{pD} \qquad (14)$$

The dilution factor will be used as a vehicle for evaluating concentration values for the partial penetration case using concentration values for the corresponding fully-penetration case. The normalized concentrations, c_{pD} and c_{fD}, and the dilution factor ζ, can be expressed as functions of several dimensionless variables as shown in Appendix A. For convenience, the important dimensionless variables are categorized as follows:

(1) Dimensionless coordinates: xD, yD and zD, defined as

$$x_D = \frac{V_s x}{2D_{xx}} = \frac{x}{2\alpha_L} \qquad (15a)$$

$$y_D = \frac{V_s y}{2D_{yy}} = \frac{y}{2\alpha_T} \qquad (15b)$$

$$z_D = \frac{V_s z}{2D_{zz}} = \frac{z}{2\alpha_z} \qquad (15c)$$

where the retarded dispersion coefficients, D_{xx}, D_{yy} and D_{zz} are computed from:

$$D_{xx} = \alpha_L V_s, \quad D_{yy} = \alpha_T V_s, \quad \text{and} \quad D_{zz} = \alpha_z V_s$$

with α_L, α_T and α_z representing the longitudinal, transverse and vertical dispersivity coefficients, respectively, and V_s representing the solute velocity.

(2) Dimensionless time: t_D, defined as

$$t_D = \frac{V_s t}{x} = \frac{t}{T} \qquad (16)$$

where t denotes the elapsed time, and T denotes the transit time of the solute. The transit time is the time taken by a solute particle to travel from the source to the observation point (x, 0, 0) on the x-axis.

(3) Dimensionless decay constant: λ_D, defined as

$$\lambda_D = \lambda T = \frac{V_s}{x} \qquad (17)$$

(4) Dimensionless standard deviation: σ_D, defined as

$$\sigma_D = \frac{\sigma}{2(\alpha_L \alpha_T)^{1/2}} \qquad (18)$$

(5) Penetration ratio of contaminant source: H/B.

(6) Aquifer thickness to vertical dispersivity ratio: B/α_z.

In general, the relative concentration for the partial penetration case can be expressed as

$$c_{pD} = \zeta c_{fD} = c_{pD}(x_D, y_D, z_D, t_D, \lambda_D, \sigma_D, \frac{H}{B}, \frac{B}{\alpha_z}) \qquad (19)$$

where c_{fD} and ζ are dimensionless functions of the form

$$c_{fD} = c_{fD}(x_D, y_D, t_D, \lambda_D, \sigma_D) \qquad (20)$$

$$\zeta = (x_D, y_D, z_D, t_D, \lambda_D, \sigma_D, \frac{H}{B}, \frac{B}{\alpha_z}) \qquad (21)$$

4 SIMPLIFIED DIMENSIONLESS RELATIONSHIPS FOR STEADY-STATE CONCENTRATION DISTRIBUTIONS ALONG THE x-AXIS

In a case where one is concerned with maximum attainable or steady-state concentration values at measurement points along the x-axis ($y = z = 0$), simplified dimensionless relationships can be derived.

These relationships may be written as

$$c^*_{pD} = \zeta^* c^*_{fD} = c^*_{pD}(x_D, \lambda_D, \sigma_D, \frac{H}{B}, \frac{B}{\alpha_z}) \qquad (22)$$

where c^*_{pD} and c^*_{fD} denote the dimensionless steady-state concentration distributions for the partial-penetration and the corresponding fully penetration cases, respectively, and ζ^* denotes the steady-state dilution factor for partial penetration. c^*_{fD} and ζ^* can be written in the form

$$c^*_{fD} = c^*_{fD}(x_D, \lambda_D, \sigma_D) \qquad (23)$$

$$\zeta^* = \zeta^*(x_D, \lambda_D, \sigma_D, \frac{H}{B}, \frac{B}{\alpha_z}) \qquad (24)$$

It is seen that c^*_{fD} is a function of three dimensionless variables, whereas ζ^* is a function of five dimensionless variables. Physical considerations suggest, however, some of the variables in equation (24) may not have significant influences on the value of the dilution factor ζ^*. Via sentivity analysis, it is concluded in Appendix A that an approximate functional expression for ζ^* may be written as

$$\zeta^* = \zeta^* \left(\frac{x}{B}, \frac{B}{\alpha_z}, \frac{H}{B}\right) \qquad (25)$$

A comparison of equations (24) and (25) shows that the dimensionless decay and standard deviation parameters would have secondary effects on the value of ζ^* for specified values of x/B, B/α_z and H/B.

5 EVALUATION OF STEADY-STATE MAXIMUM CONCENTRATION VALUES

The steady-state, three-dimensional analytical solution developed in Appendix A has been implemented into a FORTRAN computer code, EPASMOD-P. This code can be used to evaluate concentration values at any specified location and time. It can also be used to obtain dimensionless type curves (or tables of values) of the dimensionless concentration and the dilution factor. Once they have been produced, the type curves can be used as an alternative tool for providing a quick estimate or prediction of concentration values at measurement points. The case where the contaminant concentration will be maximum corresponds to the situation in which the point of measurement depicted in Figure 1 is located on the x-axis along the top of the aquifer. The maximum concentration values attainable at this point corresponds to the steady-state concentration values at the distance x from the source.

According to the analysis given in the previous section, steady-state concentration distributions along the x-axis can be represented by equation (22), which expresses c^*_{pD} for the partially-penetrating case as the product of the steady-state dilution factor, ζ^*, and the steady-state dimensionless concentration for the corresponding fully-penetrating case, c^*_{fD}. To provide a simple means for evaluating concentration values at the point of measurement, the functions c^*_{fD} and ζ^* are evaluated for realistic ranges of physical parameters.

Figure 3 shows two graphs of dimensionless concentration function c^*_{fD}. Each graph is prepared for a specified value of σ_D, and contains one family of type curves of c^*_{fD} versus x_D, for specified values of λ_D. The effect of λ_D and σ_D on values of c^*_{fD} may be noted.

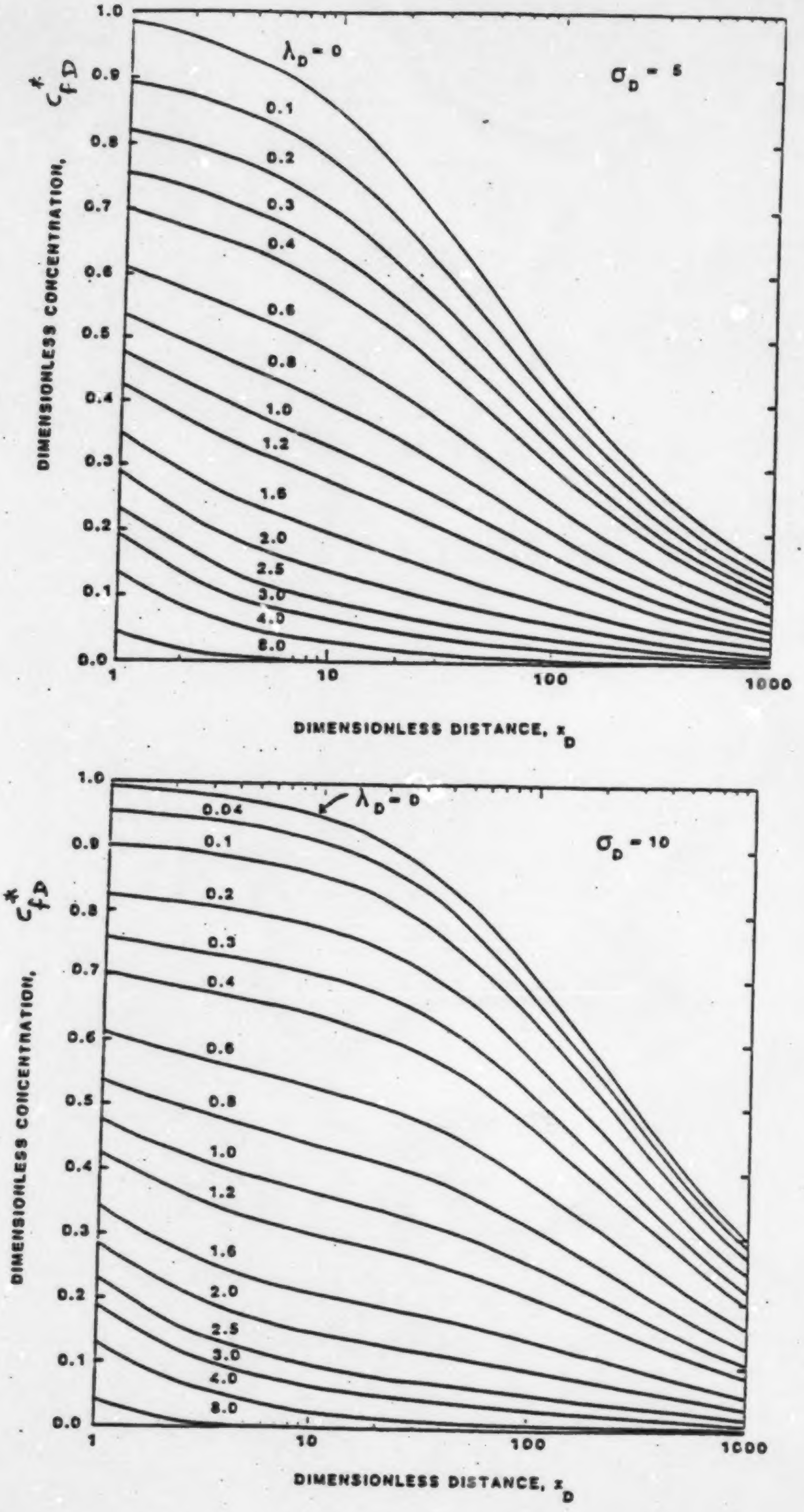


Figure 3. Type curves of dimensionless concentration, c^*_{fD} versus dimensionless distance, x_D.

As expected, λ_D has a significant influence on the type curves whereas σ_D has only a slight influence. The effect of σ_D is almost negligible for values of $x_D \leq 10$.

Figure 4 shows two graphs of dilution factor ζ^*. The first graph is prepared for a specified value of penetration ratio, $H/B = 0.25$, and contains type curves corresponding to eight selected values of B/α_z. The second graph is prepared for a specified value of ratio of aquifer thickness to vertical dispersivity, $B/\alpha_z = 25$. It contains type curves corresponding to eight selected values of H/B.

From Figure 4, the following observations of the behavior of the partial-penetration dilution factor, ζ^*, can be made.

1. The dimensionless parameters that have significant influences on ζ^* are x/B, H/B and B/α_z, which denote distance to aquifer thickness ratio, penetration ratio, and aquifer thickness to vertical dispersivity ratio, respectively.

2. For specified values of B/α_z and H/B, the ζ^*-value is unity at the source, where $x/B = 0$. As x/B increases, ζ^* decreases. The value of ζ^* approaches a lower limit as x/B reaches a value corresponding to the distance where vertical mixing is virtually completed and the concentration becomes uniform with depth The lower limit of the ζ^*-value is equal to the specified value of penetration ratio H/B. A critical distance, x_m, where the difference between ζ^* and H/B values equal to approximately 0.02 will be referred to as the "mixing length" for a given transport condition.

3. There is a relationship between the ratio of mixing length to aquifer thickness x_m/B, and the ratio of aquifer thickness to vertical dispersivity, B/α_z. This relationship is approximately linear and is defined by the following equation

$$\frac{x_m}{B} = k \cdot \frac{B}{\alpha_z} \qquad (26)$$

where k is a constant and is approximately equal to one half.

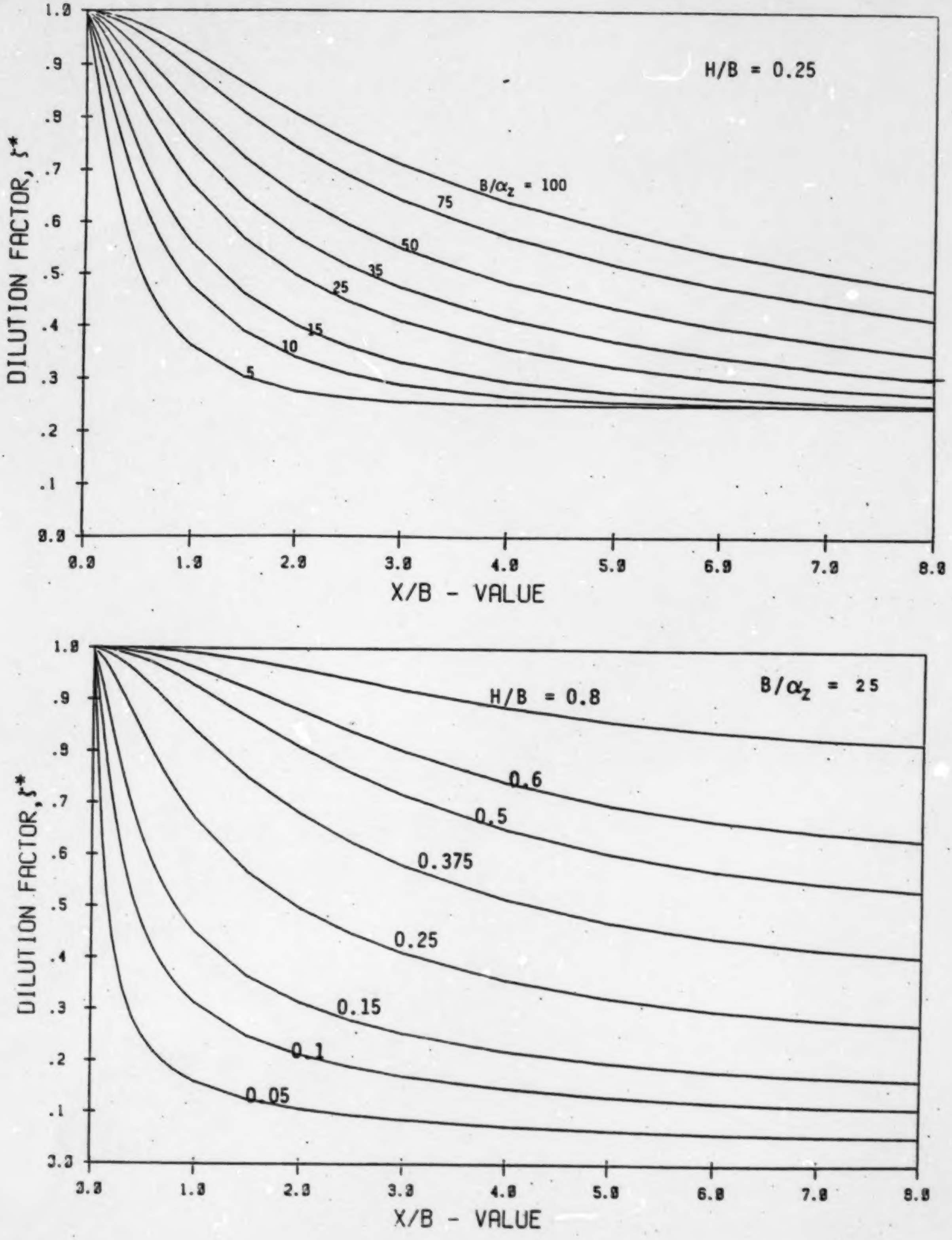


Figure 4. Type curves of dilution factor ζ^* versus ratio of distance to aquifer thickness, x/B. ($\lambda_D = 0$, $\sigma_D = 4.2$).

6 EXAMPLE CALCULATIONS: DOWN GRADIENT CONCENTRATION

For the sake of convenience in the computation of actual concentration, tabulated values of c^*_{fD} versus x_D and ζ^* versus x/B are given for fairly wide and realistic ranges of the relevant dimensionless variables. The tables of c^*_{fD} and ζ^* values are given in Appendix B. (Note that the tables should be used in preference to the graphs since the graphs may not provide sufficient accuracy in the interpolation of functional values.)

The values of steady-state concentration along the x-axis can be readily computed using either the type curves or the tables of c^*_{fD} and ζ^* values. To show the utility of the type curves and the tables, the following sample calculations are provided.

Example 1. Consider the migration of Chemical A from a land disposal unit. Let the average groundwater velocity in the flow region, V, be taken as 30 m/yr. The saturated water content and the bulk density of the aquifer material are taken as 0.35 and 1.70 g/ml, respectively. The longitudinal, transverse and vertical dispersivities, α_L, α_T and α_Z are taken as 15.4 m, 1.54 and 1.54 m, respectively. The standard deviation of the Gaussian source, , is taken as 97.3 m. The chemcial properties of Chemical A are:

Solubility, S = 3.8×10^{-3} mg/l
Distribution coefficient, K_d = 5.5×10^{-3} ml/g
Effective decay constant, λ = 3.65×10^{-7} yr^{-1}

We wish to calculate the concentration, c, at a measurement point located at x = 308 m from the landfill. We will assume that the initial source concentration, c_o, equals the solubility, S. The penetration thickness of the contaminant source and the aquifer thickness are assumed to be 10 and 40 m, respectively.

The calculation procedure consists of three steps. The first and second steps involve the determination of values of c^*_{fD} and ζ^* from the type curves using the given values of various physical parameters to compute values of the relevant dimensionless variables. The third step involves the determination of the required concentration value from known values of c^*_{fD}, ζ^* and c_o .

Step 1: Determination of c^*_{fD}-value

To use the type curves, we need to compute the values of the dimensionless parameters, x_D, ${}_D$. and ${}_D$. Using the given data, one obtains:

$$x_D = \frac{x}{2\alpha_L} = \frac{308}{2(15.4)} = 10 \quad ; \qquad {}_D = \frac{\lambda x}{V_s}$$

$$\sigma_D = \frac{\sigma}{2(\alpha_L \alpha_T)^{1/2}} = \frac{97.3}{2(15.4 \times 1.54)^{1/2}} = 10$$

Since, $\lambda = 3.65 \times 10^{-7}\ \mathrm{yr}^{-1}$

$$\text{and, } V_s = \frac{V}{R_f} = \frac{V}{1 + K_d \rho_b/\theta} = \frac{30\ \mathrm{m/yr}}{1 + 5500\mathrm{ml/g} \times 1.7\mathrm{g/ml}/0.35}$$

$$= 30\mathrm{m/yr}/26715 = 1.123 \times 10^{-3}\ \mathrm{m/yr}$$

$$\text{thus, } \lambda_D = \frac{3.65 \times 10^{-7}\mathrm{yr}^{-1} \times 308\mathrm{m}}{1.123 \times 10^{-3}\mathrm{m/yr}} = 0.10$$

Next, we use the computed value of σ_D to select the most appropriate family of type curves. The values of λ_D and x_D are then entered into the graph to determine the corresponding value of c^*_{fD}. The procedure for locating c^*_{fD}-value is illustrated in Figure 5. It is seen that $c^*_{fD} = 0.863$.

Step 2: Determination of value of dilution factor ζ^*

We elect to use the type curves of ζ^* versus x/B and select the family that corresponds to the given penetration ratio H/B of 0.25. Using the given data, we obtain:

$$\frac{x}{B} = \frac{308}{40} = 7.7$$

and

$$\frac{B}{\alpha_z} = \frac{40}{1.54} = 25.97$$

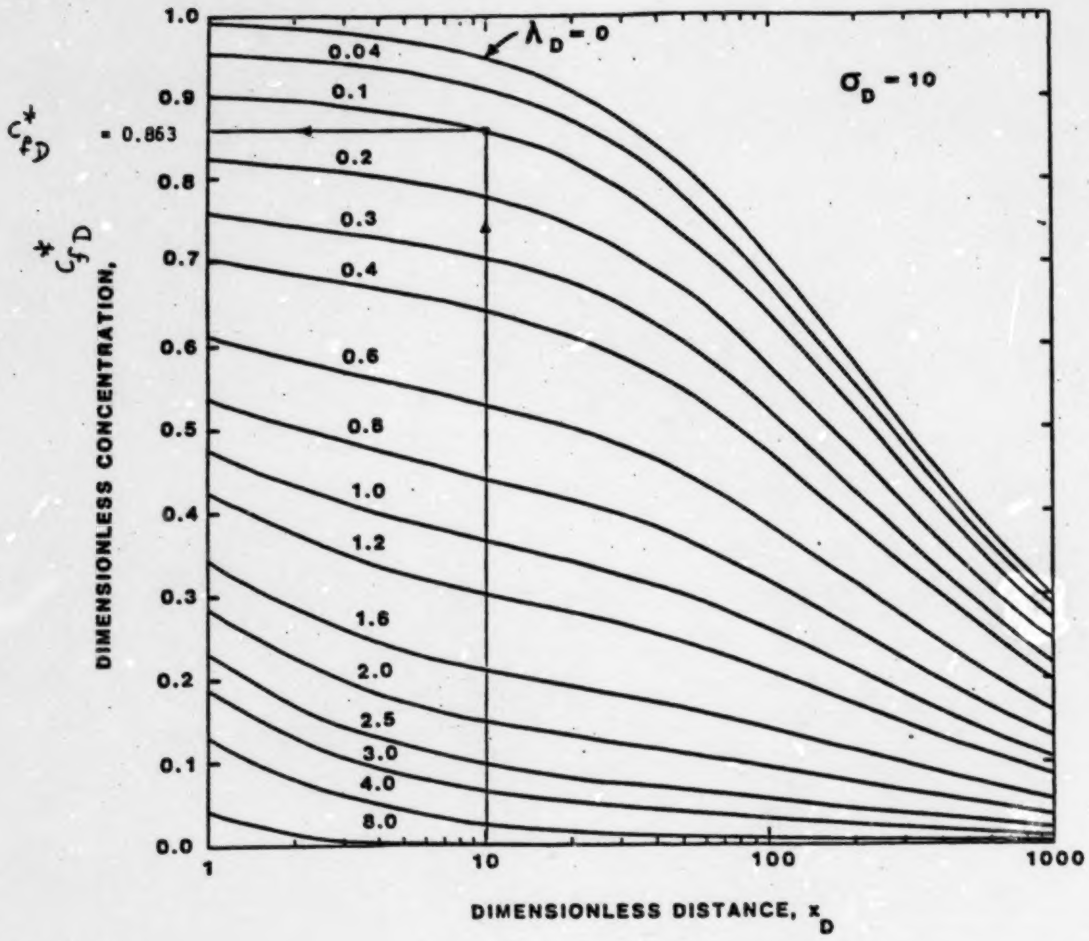


Figure 5. Determination of c_{fD}^*-value using type curves of c_{fD}^* versus x_D.

We then use the computed value of B/α_z to select the most appropriate curve, and enter the value x/B to determine the corresponding value of ζ^* as illustrated in Figure 6. From the graph, it is seen that $\zeta^* = 0.28$.

Step 3: Determination of concentration value at the measurement point

The required value of maximum attainable or steady-state concentration c^*_p at x = 308 m is obtained as follows:

$$c^*_p = c^*_{pD}\, c_o$$

$$c^*_{pD} = \zeta^* c^*_{fD} = 0.28 \times 0.863 = 0.242$$

Hence $$c^*_p = 0.242 \times 3.8 \times 10^{-3}$$

$$= 0.92 \times 10^{-3} \quad \text{mg/l}$$

Example 2. In this example, we consider the migration of Chemical B from a land disposal unit. The chemical properties of Chemical B are

Solubility, S	0.18 mg/l
Distribution coefficient, Kd	96 ml/g
Effective decay constant,	7.3×10^{-3} yr^{-1}

Suppose we wish to know the steady-state concentration at x = 154 m, given that the groundwater velocity at the site is now 300 m/yr (ten times the velocity used in Example 1). The remaining transport parameters and aquifer and contaminant source characteristics are the same as before.

Step 1: Determination of c^*_{fD}-value

From the given data, we obtain:

$$x_D = 5$$

$$\sigma_D = 10 \quad \text{(as in Example 1)}$$

$$\lambda_D = \frac{x}{v_s} = \frac{x}{v/(1 + K_d \rho_b/\theta)}$$

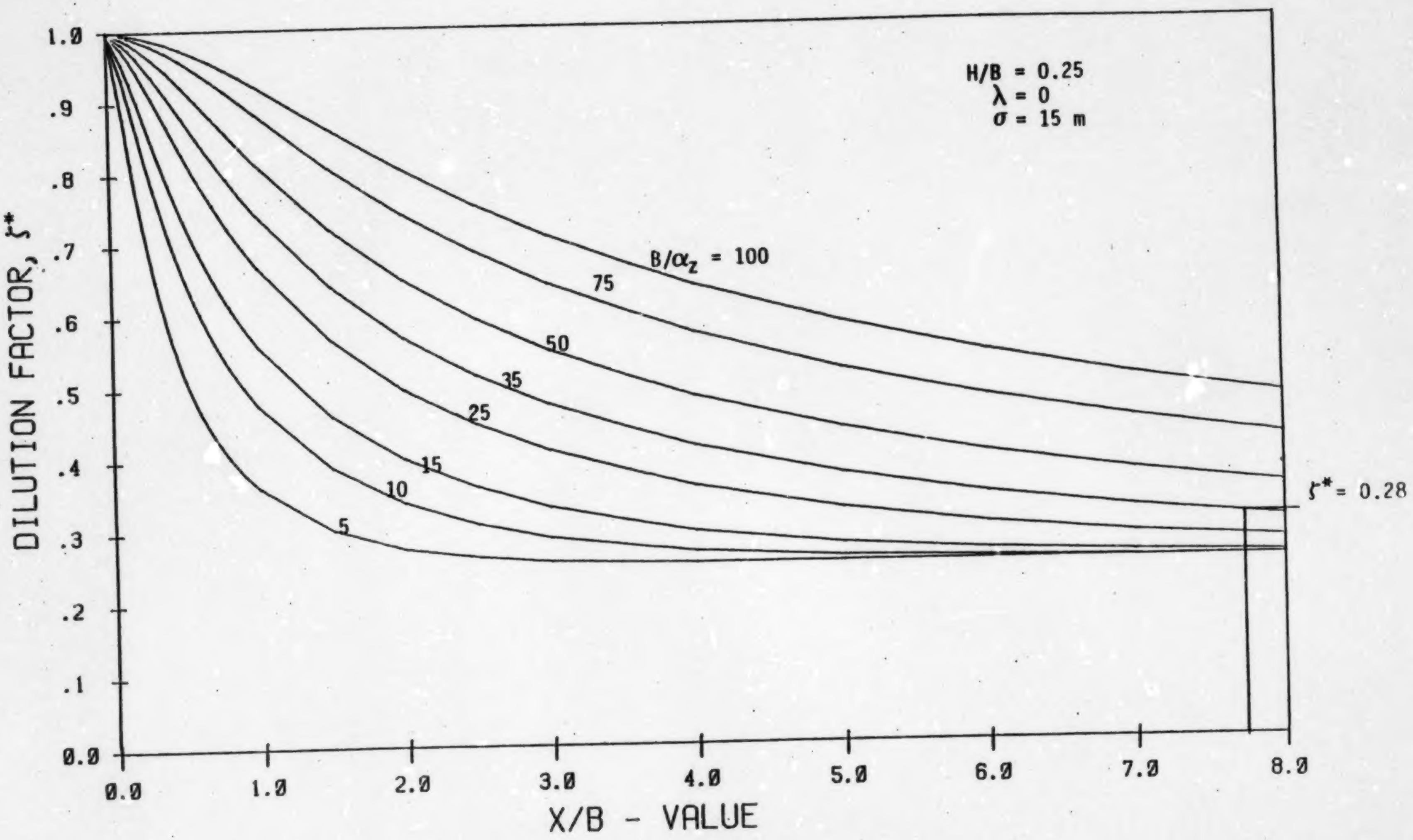


Figure 6. Determination of ζ^*-value using type curves of ζ^* versus x/B.

$$= \frac{7.3 \times 10^{-3}\text{yr}^{-1} \times 154\text{m}}{300\text{m/yr} /(1 + 96\text{ml/g} \times 1.76\text{g/ml}/0.35)}$$

$$= 1.75$$

We then use the determined value of σ_D and λ_D to locate the appropriate table in Appendix B. In this case, the most appropriate table to use is Table 7. Thus, the values of λ_D and x_D are entered into this table. The next step is to determine c^*_{fD} via linear interpolation shown below.

Given $_D = 1.75$, and using the given value of $x_D = 5$, one obtains from Table 7 in Appendix C: $c^*_{fD} = 0.241$ for $_D = 1.6$ and $c^*_{fD} = 0.207$ for $_D = 1.8$. The desired value of c^*_{fD} is that which corresponds to $_D = 1.75$, and is given by

$$c^*_{fD} = 1.75 = 0.241 - \left(\frac{0.241-0.207}{1.6 - 1.8}\right)(1.6 - 1.75)$$

$$= 0.216$$

Step 2: Determination of value of dilution factor ζ^*

From the given data, we obtain:

$$\frac{x}{B} = \frac{154}{40} = 3.85$$

$$\frac{B}{z} = \frac{40}{1.54} = 25.97$$

We use the value of H/B to locate the appropriate table in Appendix C. In this case, the most appropriate table to use is Table 3. The values of B/α_z and x/B are then entered into this table to determine the corresponding value of the dilution factor ζ^*. It follows that $^* = 0.36$.

Step 3: Determination of concentration value at the measurement point

The required value of steady-state concentration c^*p at $x = 154$ m is obtained as follows:

$$c^*_p = c^*_{pD}\, c_o$$

$$c^*_{pD} = \zeta^* c^*_{fD} = 0.36 \times 0.216 = 0.0778$$

Hence

$$c^*_p = 0.0778 \times 0.18$$

$$= 0.014 \text{ mg/l}$$

7 BACK-CALCULATION OF MAXIMUM LEACHATE CONCENTRATION

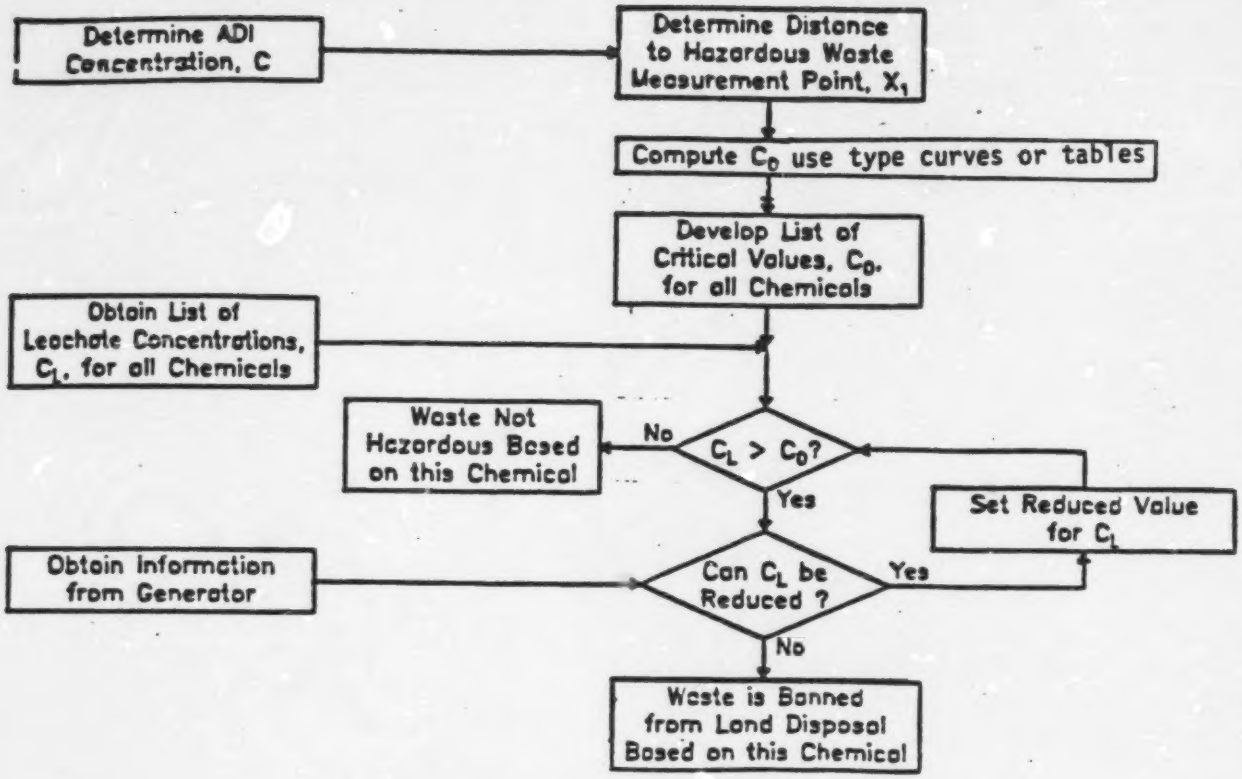
It has been shown that for any combination of parameter values, the steady-state, down-gradient concentration, $c = c_p$, at the fixed point x can be readily determined using the type curves or tables of function values. One can also determine the maximum concentration at the source, (c_o) that corresponds to a prescribed or set value of the downstream concentration, c. (We call this the back-calculation process.) Thus, if c is assumed to be a concentration value sufficient to meet a health assessment level such as the reference dose for a specific chemical, then the computed c_o will be the leachate quality required to yield the reference dose at the fixed distance. This "back calculated" leachate concentration can then be compared to expected values from a leach test or by a comparison to a maximum solubility value.

The above examples illustrate the calculation of steady-state concentration distributions along the x-axis for a given set of input parameters using the steady-state solution. However, rather than specify one "reasonable worst case" land disposal scenario, EPA has developed a procedure that accommodates the possible variation in environmental settings, uncertainties in chemical specific properties, and uncertainties in the range of impact of engineered system releases from land disposal units. This procedure termed Monte Carlo simulation is most suitable for investigating the land disposal restrictions process.

8 LOGIC FLOW CHART FOR LAND DISPOSAL SCREENING

A logic flow chart for the screening procedure is presented in Figure 7. The flow chart combines the steps EPA must take in developing and implementing the procedure with the steps generators and owner/operators must take in determining whether or not their waste can be land disposed.

Using the information available at each critical step in the flow chart (diamond shaped boxes), generators and owner/operators must answer the following questions:



Determine ADI Concentration, C
Determine Distance to Hazardous Waste Measurement Point, X1
Compute C0 use type curves or tables
Develop List of Critical Values, C0, for all Chemicals
Obtain List of Leachate Concentrations, CL, for all Chemicals
Waste Not Hazardous Based on this Chemical
No
CL > C0?
Yes
Set Reduced Value for CL
Obtain Information from Generator
Can CL be Reduced ?
Yes
No
Waste is Banned from Land Disposal Based on this Chemical

FIGURE 7

SCREENING PROCEDURE FLOW CHART

1. Does the leachate quality for each constituent in the hazardous waste indicate that it is acceptable for land disposal?

2. If the leachate quality indicates that the hazardous waste is not acceptable for land disposal, can it be pretreated or treated such that the leachate quality indicates that the hazardous waste is acceptable for land disposal?

The answers to these questions lead to yes or no decisions and dictate the action to be taken. Further, question two provides a point where treatment of wastes can be taken into account prior to making a final decision. A detailed, step-by-step description of the screening procedure is given below. The parentheses indicate who is responsible for each step, EPA or the generator/owner/operator (Gen;O/O).

PART A: Restriction of Hazardous Waste From Land Disposal

Step 1 (EPA).. Determine "Reference Dose Concentration

For each individual constituent in the waste, there must be an appropriate toxicologically based limit expressed in concentration units. This value, once determined, is set to be the steady-state down gradient concentration, c, at the fixed measurement point (x).

The steady-state value downgradient, c, will be pre-determined by the levels evaluated in a risk assessment of each constituent in the waste. The maximum concentration of each constituent at the point of measurement cannot exceed either reference dose for non-carcinogens or the a dose at a 10^{-6} risk level for carcinogens.

Step 2 (EPA): Determine Distance to Measurement Point

The lateral, downgradient distance from the land disposal facility to the measurement point, x, must be specified. At this point, the presence of a constituent at concentrations exceeding a health assessment level will result in a waste being banned from land disposal. In this approach, we are setting x equal to 500ft.

Step 3 (EPA).. Compute c_o

This step can be achieved using the type curves or tables of dimensionless functions, c^*_{fD} and *.

For the determination of c^*_{fD}-value, input values of the dimensionless parameters x_D, λ_D, and σ_D are required. By definition, these dimensionless parameters depend on the distance, x, the longitudinal and transverse dispersivities, α_L and α_T, the standard deviation of the Gaussian distribution at the source, σ, the chemical decay constant, λ, and the transit time T ($T = x/V_s$).

For the determination of $\mathcal{J}^*$-value, input values of x/B, H/B, and B/α_z are required. By definition, these dimensionless parameters depend on the distance, x, the aquifer thickness, B, the penetration thickness of the source, H, and the vertical dispersivity, α_z.

Values of the longitudinal, the transverse, and the vertical dispersivities can be determined from published data. In the field, the longitudinal dispersivity may vary from 5 to 100 m. The transverse dispersivity value is usually taken to be the same as the vertical dispersivity. The value of lateral dispersivity is a fraction of the value of longitudinal dispersivity. The ratio of α_L to α_T may vary from 2 to 20.

The standard deviation has a similar range of variation to α_L and α_T. For a conservative prediction of downstream concentration, the value of should be selected to be at least the same or twice the longitudinal dispersivity. The effective decay constant, λ, is chemical specific. Assuming simple hydrolysis, λ, can be determined using the procedures described in detail in Section 9.

Step 4 (EPA): Develop and Promulgate List of Screening levels, c_o, for Land Disposal Restrictions Determinations for All Chemicals

Through the use of the computer model, EPASMOD, EPA will develop a list of c_o values for all chemical constituents. The c_o values can also be computed using the dimensionless functions and tabulated values. The c_o values can be viewed as maximum acceptable extract concentrations for each waste constituent if the waste is to be considered acceptable for land disposal.

Step 5 (Gen;0/0).. Determine The Leachate Concentration, c_L

The concentration in the leachate c_L will be determined by a test similar to the EPA extraction procedure (EP), developed specifically to address organic as well as inorganic constituents. (This test, is termed the Toxicity Characteristic Leaching Procedure.) c_L must be determined for each chemical constituent in the waste for which the Agency has established values for c_o. This step is the responsibility of the waste generator.

Step 6 (Gen;0/0).. Is $c_L > c_o$?

Once a generator determines the actual leachate concentration, c_L, of each chemical constituent in a waste, a simple comparison is made with the list of maximum acceptable leach concentrations, co, developed by EPA in Step 4. If, for each chemical constituent in the waste, the leachate concentration, c_L, is not greater than the listed maximum acceptable concentration, c_o, for that constituent, then the waste can be land disposed. If, the leachate concentration, c_L, for any constituent in the waste exceeds the listed maximum acceptable concentration, c_o, for that constituent, the waste is banned from land disposal.

Step 7 (Gen;0/0): Can c_L be Reduced?

If it is possible for the generator to reduce the leachate concentration via pretreatment or treatment such that the resulting leachate concentration, c_L, for each chemical constituent in the waste is no longer greater than the listed maximum acceptable concentration, c_o, then the waste (following pretreatment or treatment) can be land disposed as a hazardous waste. If the leachate concentration, c_L.,for any chemical constituent in the waste can not be reduced via pretreatment or treatment to a level equal to or less than it's listed maximum acceptable concentration, c_0, the waste is banned from land disposal.

9 CALCULATION OF EFFECTIVE DECAY CONSTANT

The effective decay constant, λ , is chemical specific. Assuming simple hydrolysis, , can be determined from

$$\lambda = \left(\frac{\lambda_1 \theta + \lambda_2 K_d \rho_b}{\theta + K_d \rho_b}\right) \qquad (27)$$

where λ = lumped first-order degradation rate constant, yr^{-1}

λ_1 = first-order hydrolysis rate constant for the dissolved constituent, yr^{-1}

λ_2 = first-order hydrolysis rate constant for the sorbed constituent, yr^{-1}

K_d = distribution coefficient, $cm^3 g^{-1}$

θ = volumetric water content of soil, cm^3/cm^3

ρ_b = soil bulk density, g/cm^3

and $$R_f = 1 + \frac{k_d \rho_b}{\theta}$$

From process theory (Mill et al., 1981) we know that for hydrolysis, the decay constant for the i phase can be determined from:

$$\lambda_i = K_a[H^+] + K_n + K_b[OH^-], \quad i = 1,2 \tag{28}$$

where K_a = second order rate constant for acid catalyzed hydrolysis, $M^{-1}\ yr^{-1}$
K_n = neutral hydrolysis rate constant, yr^{-1}
K_b = second order rate constant for base catalyzed hydrolysis, $M^{-1}\ yr^{-1}$
$[H^+]$ = hydrogen ion concentration, M
$[OH^-]$ = hydroxyl ion concentration, M

Because both the sorbed and dissolved states exist we must develop expressions for λ_1 and λ_2 The dissolved case is simply as depicted above. The pH of the groundwater must be known. For the sorbed case, an "effective" pH of the sorbent must be known, i.e., what is the pH of the adsorbing surface? This can vary depending upon the soil type but a conservative estimate is one pH unit less than the bulk fluid. Evidence also exists to suggest alkaline hydrolysis does not operate for the sorbed state (Wolfe, 1984). Using this approximation we have:

$$\lambda_2 = 10K_a\ [H^+] + K_n \tag{29}$$

We can now write

$$\lambda = (\frac{(K_a[H^+] + K_n + K_b[OH^{-1}])\theta + (10K_a[H^+] + K_n)\ K_d \rho_b}{\theta + K_d \rho_b} \tag{30}$$

From this analysis it is clear that two things are required to compute λ. First the second-order rate constants must be known, measured, or estimated and the pH of the groundwater must be known.

Other parameter values required are: the bulk density, ρ_b, saturated moisture content, θ, the solute velocity, V_s, and the distribution coefficient, K_d. The bulk density, ρ_b and the saturated moisture content, θ, vary over a relatively narrow range and the flow velocity, V, may be quite variable. The development of these data are described in the discussion of Monte Carlo Uncertainty Analysis.

The problem remains to estimate the distribution coefficient, K_d, needed for both the overall rate expression and the retardation coefficient, R_f. In general, this term is dependent upon both the chemical properties and the sorbent properties. For organic, hydrophobic chemicals K_d is commonly correlated to the organic carbon fraction of the sorbent (Karickhoff, 1979; Lyman, 1982). Thus, if one knows the normalized distribution coefficient for organic carbon, K_{oc}, for a specific chemical and the fraction organic carbon, f_{oc} for the soil then,

$$K_d = f_{oc}K_{oc} \tag{31}$$

Values for Koc are often available for chemicals and in many cases can be estimated from Kow (octanol-water partition coefficient) (Karickhoff, 1979). K_{ow} values can be either measured or calculated from well-known and usually reliable relationships (Lyman et al., 1982; Mill et al., 1984). The problem remains to specify the organic carbon content, f_{oc}, of the saturated zone. This value is expected to be quite low and can be determined from surveys, published data, or from engineering judgement. Caution must be exercised in assigning a very low value for f_{oc}. At such values (e.g., f_{oc} <.001 - .005) other sorbent characteristics contribute more to sorption. The soil mineral content, for example, will influence sorption. In any case, our assumptions are conservative in that estimated K_d values will be smaller than if other mechanisms were included. Sample calculations of and R are given below.

Example Calculations for λ and R_f

Given: groundwater pH at 6.5

$\theta = 0.35$
$f_{oc} = 0.001$
$\rho_b = 1.20$ gm cm^{-3}

chemical is X

chemical properties
water solubility, 700 mg/l

$K_a = 5.04 * 10^{-4}$ M^{-1} hr^{-1}
$K_n = 2.5 * 10^{-3}$ hr^{-1}
$K_b = 1638$ M^{-1} hr^{-1}
Log $K_{ow} = 2.55$

Find $\lambda_1 = K_a[H^+] + K_n + K_b[OH]$

$\lambda_2 = 10\ K_a[H^+] + K_n$

at pH = 6.5 $[H^+] = 3.16 * 10^{-7}$ M
$[OH-] = 3.16 * 10^{-8}$ M

Converting K_a, K_n, K_b to units of yr^{-1} we have

$$K_a = 5.04*10^{-4} M^{-1} hr^{-1} * 8.76\ hr\ yr^{-1} * 10^3 = 4.415\ M^{-1}\ yr^{-1}$$
$$K_n = 2.5*10^{-3}\ hr^{-1} * 8,760\ hr\ yr^{-1} * 10_3 = 21.9\ yr^{-1}$$
$$K_b = 1638 M^{-1} * 8.76*10^3\ hr\ yr^{-1} = 14.35*10^6\ M^{-1}\ yr^{-1}$$

Now for $\lambda_1 = 4.415 * 3.16*10^{-7} + 21.9 + 14.35*10^6 * 3.16*10^{-8}$

$$\lambda_1 = 1.4*10^{-6} + 21.9 + .453$$
$$\lambda_1 = 22.4\ yr^{-1}$$
$$\lambda_2 = 10 \times 4.415[10^{-7}] + 21.9$$
$$\lambda_2 = 21.9\ yr^{-1}$$

Find: K_d

From Karickhoff (1979) we have

$$\log K_{oc} = 1.00 \log K_{ow} - 0.21$$

so $\log K_{oc} = 1.00 * 2.55 - 0.21$

and $K_{oc} = 219$

$$K_d = f_{oc} * K_{oc} = .001 * 219 = 0.219$$

Finally, $$\lambda = \frac{(22.4 * 0.35 + 21.9 * 0.219 * 1.2)}{0.35 + 0.219 * 1.2}$$

$$\lambda = 22.19\ yr^{-1}$$

and $$R = (1 + \frac{.219 * 1.2}{0.35}) = 1.75$$

10 SUMMARY AND OBSERVATIONS

The proposed approach is conservative but not unrealistic, since it accommodates the opportunity for degradation (due to hydrolysis), retardation, and dispersion in the longitudinal, lateral and vertical directions. The proposed procedure does not require considerable effort to execute. A careful analysis of the data required to run the model is presented in the following section on Monte Carlo simulation techniques.

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#2
APP A

APPENDIX A

DEVELOPMENT OF THREE-DIMENSIONAL ANALYTICAL SOLUTIONS FOR CONTAMINANT TRANSPORT

INTRODUCTION

The model described in the main body of this report is based on three-dimensional, transient and steady-state, analytical solutions for solute transport from a distributed source in a homogeneous and isotropic aquifer through which there is uniform groundwater flow. These solutions are derived herein.

GOVERNING EQUATIONS

Consider the region with the distributed source shown in Figure 1.1. The advective-dispersive equation for the transport of a nonconservative contaminant in an adsorbing homogeneous and isotropic porous medium with fully-saturated uniform flow can be written as

$$V_s \frac{\partial c}{\partial x} - D_x \frac{\partial^2 c}{\partial x^2} - D_Y \frac{\partial^2 c}{\partial y^2} - D_z \frac{\partial^2 c}{\partial z^2} + \lambda_c + Ic + \frac{\partial c}{\partial t} = 0 \qquad (1)$$

$$0 \leq x \leq \infty \qquad -\infty \leq y \leq \infty \qquad 0 \leq z \leq B$$

where D_x, D_y and D_x are retarded dispersion coefficients in the longitudinal, x, transverse, y, and vertical, z, directions, respectively ($D_x \equiv D_{xx}$, $D_y \equiv D_{yy}$, and $D_z \equiv D_{zz}$), V_s is the retarded solute velocity, λ is the first-order decay coefficient, c is the solute concentration, and t is the elapsed time.

The initial and boundary conditions of the problem may be expressed as follows:

$$c\,(x,\ y,\ z,\ 0) = 0 \qquad (2a)$$

$$c\,(\infty,\ y,\ z,\ t) = 0 \qquad (2b)$$

$$c\,(x,\ \infty,\ z,\ t) = 0 \qquad (2c)$$

$$c\,(x,\ -\infty,\ z,\ t) = 0 \qquad (2d)$$

$$\frac{\partial c}{\partial z}\,(x,\ y,\ 0,\ t) = 0 \qquad (2e)$$

$$\frac{\partial c}{\partial z}\,(x,\ y,\ B,\ t) = 0 \qquad (2f)$$

$$c\,(0,\ y,\ z,\ t) = c_0 \exp\left(\frac{-Y^2}{2\sigma^2}\right) U\,(z) \qquad (2g)$$

where c_0 is the peak concentration at the source, σ is the standard deviation of the Gaussian distribution centered at $x = y = 0$, and $U(z)$ is the unit step function defined as

$$U(z) = 1 \quad , H_1 \le z \le H_2$$

$$U(z) = 0 \quad , z > H_1 \text{ or } z > H_2.$$

DERIVATION OF TRANSIENT ANALYTICAL SOLUTION

To derive the transient analytical solution for a Gaussian distributed source in y with the concentration at any point y for $x = 0$ being uniform between $z = H_1$ and $z = H_2$, we will first derive a fundamental solution for an infinitely thin Gaussian source located at depth $z = z'$. We will then integrate this solution with respect to z' between the depth limits H_1 and H_2.

The fundamental solution must satisfy equation (1) and the initial and boundary conditions (2a)-(2f), as well as the following source boundary condition:

$$c\ (0,\ y,\ z,\ t) = (H_2 - H_1)\ c_0 \exp\left(\frac{-y^2}{2\sigma^2}\right) \delta\ (z-z') \tag{2h}$$

where c_0 and σ are the peak concentration and the standard deviation of the Gaussian distribution, respectively, and $\delta(z-z')$ is the Dirac delta function.

We introduce the following exponential Fourier transform in the y-space:

$$\bar{c}\ (x,\ \alpha,\ z,\ t) = \int_{-\infty}^{\infty} c\ (x,\ y,\ z,\ t) \exp\ (-i\ \alpha\ y)\ dy$$

$$= F_e\ [\ c\ (x,\ y,\ z,\ t)] \tag{3}$$

Applying the above transform to equation (1) and making use of boundary conditions (2c) and (2d), one obtains:

$$\frac{\partial \bar{c}}{\partial t} + V_s \frac{\partial \bar{c}}{\partial x} - D_x \frac{\partial^2 \bar{c}}{\partial x^2} + D_y \alpha^2 \bar{c} - D_z \frac{\partial^2 \bar{c}}{\partial z^2} + \lambda \bar{c} + Ic = 0$$

By means of the exponential transform, the remaining initial and boundary conditions (2a), (2b), (2e), (2f), and (2h) can be converted to

$$\bar{c}\ (x, \alpha, z, o) = 0 \quad (5a); \quad \bar{c}\ (\infty, \alpha, z, t) = 0 \tag{5b}$$

$$\frac{\partial \bar{c}}{\partial z}\ (x, \alpha, B, t) = 0 \quad (5c); \quad \frac{\partial \bar{c}}{\partial z}\ (x, \alpha, o, t) = 0 \tag{5d}$$

$$\bar{c}\ (o, \alpha, z, t) = (2\pi)^{\frac{1}{2}}\ m\sigma \exp \left(\frac{-\sigma^2 \alpha^2}{2}\right) \delta(z-z') \tag{5e}$$

where, for the sake of convenience, we let $m = (H_2-H_1)c_o$. Note that equation (5e) was obtained using the relation:

$$F_e \left[\exp\left(-\frac{y^2}{4c}\right)\right] = 2\ (\pi c)^{\frac{1}{2}} \exp\ (-c\ \alpha^2) \tag{6}$$

Next, we introduce the finite Fourier cosine transform in the z-space:

$$\bar{\bar{c}}\ (x, \alpha, n, t) = \int_0^B \bar{c}\ (x, \alpha, z, t) \cos \left(\frac{n\pi z}{B}\right) dz \tag{7}$$

Using this transform, equation (4), with (5c) and (5d), and the remaining initial and boundary conditions (5a), (5b), and (5e) can be converted to

$$\frac{\partial \bar{\bar{c}}}{\partial t} + V_s \frac{\partial \bar{\bar{c}}}{\partial x} - D_x \frac{\partial^2 \bar{\bar{c}}}{\partial x^2} + D_y \alpha^2 \bar{\bar{c}} + \frac{n^2 \pi^2}{B^2} D_z \bar{\bar{c}} + \lambda \bar{\bar{c}} + Ic = 0 \tag{8}$$

and
$$\bar{\bar{c}}\ (\infty, \alpha, z, t) = 0 \tag{9a}$$

$$\bar{\bar{c}}\ (x, \alpha, n, o) = 0 \tag{9b}$$

$$c\ (o, \alpha, n, t) = (2\pi)^{\frac{1}{2}}\ m\sigma \exp \left(-\frac{\sigma^2 \alpha^2}{2}\right) \cos \left(\frac{n\pi z'}{B}\right) \tag{9c}$$

Finally, we introduce the Laplace transform in the time domain:

$$\bar{\bar{\bar{c}}}\ (x, \alpha, n, p) = \int_0^\infty \exp\ (-pt)\ \bar{\bar{c}}\ (x, \alpha, n, t)\ dt \tag{10}$$

Using the Laplace transform, equation (8) with (9a), and the remaining boundary conditions (9b) and (9c) can be converted to

$$p\bar{\bar{\bar{c}}} + V_s \frac{d\bar{\bar{\bar{c}}}}{dx} - D_x \frac{d^2\bar{\bar{\bar{c}}}}{dx^2} + D_y \alpha^2 \bar{\bar{\bar{c}}} - \frac{n^2\pi^2}{B^2} D_z \bar{\bar{\bar{c}}} + \lambda \bar{\bar{\bar{c}}} + Ic = 0 \tag{11}$$

and

$$\bar{\bar{\bar{c}}}\,(\infty, \alpha, n, p) = 0 \tag{12a}$$

$$\bar{\bar{\bar{c}}}\,(o, \alpha, n, p) = \frac{(2\pi)^{\frac{1}{2}}}{p}\, m\sigma \exp\left(\frac{-\sigma^2\alpha^2}{2}\right) \cos\left(\frac{n\pi z'}{B}\right) \tag{12b}$$

Equation (11) can rearranged to yield:

$$\frac{d^2\bar{\bar{\bar{c}}}}{dx^2} - \frac{V_s}{D_x}\frac{d\bar{\bar{\bar{c}}}}{dx} - \frac{1}{D_x}\left(p + \lambda + I + D_y\alpha^2 + \frac{n^2\pi^2}{B^2} D_z\right)\bar{\bar{\bar{c}}} = 0 \tag{13}$$

The general solution to the second-order, ordinary, homogeneous differential equation (13) is given by

$$\bar{\bar{\bar{c}}} = A_{exp}(r_+) + B_{exp}(r_- x) \tag{14}$$

where

$$r_+ = \frac{V}{2D_x} + \frac{1}{2}\left[\frac{V_s^2}{D_x^2} + \frac{4}{D_x}\left(p + \lambda + I + D_y\alpha^2 + \hat{n}D_z\right)\right]^{1/2}$$

$$r_- = \frac{V}{2D_x} + \frac{1}{2}\left[\frac{V_s^2}{D_x^2} + \frac{4}{D_x}\left(p + \lambda + I + D_y\alpha^2 + \hat{n}D_z\right)\right]^{1/2}$$

and

$$\hat{n} \quad \frac{n^2\pi^2}{B^2}$$

Because the solution must be bounded as x → D according to (12a), the constant of integration A = 0. Boundary condition gives:

$$B = \frac{(2\pi)^{1/2}m}{p}\, \sigma \exp\left(-\frac{\sigma^2\alpha^2}{2}\right) \cos\left(\frac{n\pi z'}{B}\right) \tag{15}$$

Substitution of A = 0 and B given by (15) into (14) gives, after slight algebra:

$$\bar{\bar{\bar{c}}} = (2\pi)^{1/2} m\, \sigma \exp\left(-\frac{\sigma^2\alpha^2}{2}\right) \cos\left(\frac{n\pi z'}{B}\right) \exp\left(\frac{V_s x}{2D_x}\right) \tag{16}$$

$$\cdot \frac{1}{p} \exp\left[-\left\{ \frac{p + \lambda + I + V_s^2/4D_x + \alpha^2 D_y + \hat{n} D_z}{D_x} \right\}^{1/2} x \right]$$

the subsidiary solution (15) must now be inverted. We will apply the inverse Laplace transform first. Although the function

$$\frac{1}{p} \exp\left[-\tfrac{1}{2} \left\{ \cdot \right\}^{1/2} x \right]$$

is easily inverted using tabulated results (see Carslaw and Jaeger, 1959, p. 495), the resulting function is complicated and will therefore make application of the inverse Exponential Fourier transform difficult. Therefore, we will make use of the following relations:

$$L^{-1} \left[\exp\left(-a(p + b)^{1/2} \right) \right] = \frac{a}{2\pi^{1/2} t^{3/2}} \exp\left(-bt - \frac{a^2}{4t}\right) \tag{17a}$$

and

$$L^{-1} \left[\frac{1}{p} \bar{f}(p) \right] = \int_0^t f(\tau)\, d\tau \tag{17b}$$

where the shift theorem was made use of in the first inverse. Using the results, the inverse Laplace transform of (16) is

$$\bar{\bar{c}}(x, \alpha, n, t) = \frac{m\sigma x}{(2D_x)^{1/2}} \exp\left(-\frac{\sigma^2\alpha^2}{2}\right) \cos\left(\frac{n\pi z'}{B}\right) \exp\left(\frac{V_s x}{2D_x}\right) \tag{18}$$

$$\cdot \int_0^t \frac{1}{\tau^{3/2}} \exp\left[- \frac{V_s^2}{4D_x} + \alpha^2 D_y + \hat{n} D_z + \lambda + I)\, \tau - \frac{x^2}{4D_x \tau} \right] d\tau$$

Although the above integral can be evaluated analytically, the resulting expression will make inversion with respect to α extremely difficult. Thus, the time integral will be retained.

The inverse Exponential Fourier transform will be applied next. To facilitate inversion, (18) can be written in the form:

$$\bar{\bar{c}}(x, \alpha, n, t) = \frac{m\sigma x}{(2D_x)^{1/2}} \exp\left(\frac{V_s x}{2D_x}\right) \cos\left(\frac{n\pi z'}{B}\right) \tag{19}$$

$$\cdot \int_0^t \frac{1}{\tau^{3/2}} \exp\left\{ -\alpha^2 \left(D_y \tau + \frac{\sigma^2}{2}\right) - \left(\frac{V_s^2}{2D_x} + \hat{n} D_z + \lambda + I\right) \tau - \frac{x^2}{4D_x \tau} \right\} d\tau$$

We need the following inverse Exponential Fourier transform (Churchill, 1979, p. 472)

$$F_e^{-1} \left[\exp \left\{ -\alpha^2 \left(D_y\tau + \frac{\sigma^2}{2} \right) \right\} \right] = \frac{\exp \left[-y^2/4(D_y\tau + \sigma^2/2) \right]}{2 \left[\pi(D_y\tau + \sigma^2/2) \right]^{1/2}} \qquad (20)$$

Using (20) the inverse of (19) with respect to α is:

$$\bar{c}\,(x, y, n, t) = \frac{m\sigma x}{2(2\pi D_x)^{1/2}} \exp \left(\frac{V_s x}{2D_x} \right) \cos \left(\frac{n\pi z'}{B} \right)$$

$$\cdot \int_0^t \frac{1}{\tau^{3/2} \left(D_y\tau + \frac{\sigma^2}{2} \right)^{1/2}} \exp \left(- \frac{x^2}{4D_x\tau} - \frac{y^2}{4\left(D_y\tau + \frac{\sigma^2}{2} \right)} - \left(\frac{V_s^2}{4D_x} + \hat{n}\, D_z + \lambda + I \right) \tau \right) d\tau \qquad (21)$$

Finally, our fundamental solution will be completed after making use of the following inversion formula for the Finite Fourier Cosine transform:

$$c\,(x, y, z, t) = \bar{c} \left(\frac{x, y, n = 0, t}{B} \right) + \frac{2}{B} \sum_{n=1}^{\infty} \bar{c}\,(x, y, n, t) \cos \left(\frac{n\pi x}{B} \right) \qquad (22)$$

Substitution of (21) into (22) gives

$$c\,(x, y, z, t) = \frac{m\sigma x}{2B(2\pi D_x)^{1/2}} \exp \left(\frac{V_s x}{2D_x} \right) \left[\int_0^t \frac{1}{\tau^{3/2} \left(D_y\tau + \frac{\sigma^2}{2} \right)^{1/2}} \right.$$

$$\exp \left(- \frac{x^2}{4D_x\tau} - \frac{y^2}{4\left(D_y\tau + \frac{\sigma^2}{2} \right)} - \frac{V_s^2\tau}{4D_x} - \lambda\tau - I\tau \right) d\tau + 2 \sum_{n=1}^{\infty} \cos \left(\frac{n\pi z}{B} \right) \cos \left(\frac{n\pi z'}{B} \right) \qquad (23)$$

$$\left. \cdot \int_0^t \frac{1}{\tau^{3/2} \left(D_y\tau + \frac{\sigma^2}{2} \right)^{1/2}} \exp \left(- \frac{x^2}{4D_x\tau} - \frac{y^2}{4\left(D_y\tau + \frac{\sigma^2}{2} \right)} - \frac{V_s^2\tau}{4D_x} - \frac{n^2\pi^2 D_z\tau}{B^2} - \lambda\tau - I\tau \right) d\tau \right]$$

Having obtained the fundamental solution, the remaining step is to use it to obtain the final solution by converting the infinitely thin Gaussian source to the finite Gaussian source of equal strength and extending from $z = H_1$ to $z = H_2$. This is achieved by integrating (23) with respect to z' between the limits H_1 and H_2 and dividing by the source thickness, H_2-H_1. The result is given by

$$c\,(x,\,y,\,z,\,t) = \frac{c_0\sigma x}{2(2\pi D_x)^{1/2}} \exp\left(\frac{V_s x}{2D_x}\right) \left[\frac{H_2-H_1}{B} \int_0^t \frac{1}{\tau^{3/2}(D_y\tau + \frac{\sigma^2}{2})^{1/2}} \right. \tag{24}$$

$$\cdot \exp\left(- \frac{x^2}{4D_x\tau} - \frac{y^2}{4(D_y\tau + \frac{\sigma^2}{2})} - \frac{V_s^{\,2}\tau}{4D_x} - \lambda\tau - I\tau \right) d\tau$$

$$+ \frac{2}{\pi} \sum_{n=1}^{\infty} \frac{1}{n} \cos\left(\frac{n\pi z}{B}\right) \left[\sin\left(\frac{n\pi H_2}{B}\right) - \sin\left(\frac{n\pi H_1}{B}\right) \right] \int_0^t \frac{1}{\tau^{3/2}(D_y\tau + \frac{\sigma^2}{2})^{1/2}}$$

$$\left. \cdot \exp\left\{ - \frac{x^2}{4D_x\tau} - \frac{y^2}{4(D_y\tau + \frac{\sigma^2}{2})} - \left(\frac{V_s^{\,2}}{4D_x} + \frac{n^2\pi^2 D_z}{B^2} + \lambda + I\right)\tau \right\} d\tau \right]$$

Equation (24) may be expressed in a simple form as

$$c_p(x,\,y,\,z,\,t) = \frac{H}{B}\, c_f(x,\,y,\,t) + \Delta c_p(x,\,y,\,z,\,t) \tag{25}$$

where we have assumed that $H_1 = 0$ and $H_2 = H$ (i.e., the source extends from the top of the aquifer through the thickness H), $c_p(x, y, z, t)$ now replaces $c(x, y, z, t)$ and $c_f(x, y, t)$ and $\Delta c_p(x, y, z, t)$ are defined as

$$c_f(x,\,y,\,t) = \xi \int_0^t \frac{1}{\tau^{3/2}(2\sigma^2 + 4D_y\tau)^{1/2}}$$

$$\cdot \exp\left(- \frac{x^2}{4D_x\tau} - \frac{y^2}{4D_y\tau + 2\sigma^2} - \eta\tau\right) d\tau \tag{26}$$

$$\Delta c_p(x,\,y,\,z,\,t) = \frac{2}{\pi} \sum_{n=1}^{\infty} \frac{1}{n} \cos\left(\frac{n\pi z}{B}\right) \sin\left(\frac{n\pi H}{B}\right) \tag{27}$$

$$\cdot\, \xi \int_0^t \frac{1}{\tau^{3/2}(2\sigma^2 + 4D_y\tau)^{1/2}} \cdot \exp\left(- \frac{x^2}{4D_x\tau} - \frac{y^2}{4D_y\,\tau + 2\sigma^2} - \beta_n\tau\right) d\tau$$

in which

$$\xi = \frac{c_0\sigma x}{(2\pi D_x)^{1/2}} \exp\left(\frac{V_s x}{2D_x}\right) \tag{28}$$

$$\eta = \frac{V_s^{\,2}}{4D_x} + \lambda + I \tag{29}$$

$$\beta_n = \eta + \frac{n^2\pi^2 D_z}{B^2} \tag{30}$$

It should be noted that $c_f(x, y, t)$ is identical to the two-dimensional analytical solution for the case where the Gaussian source fully penetrates the entire aquifer thickness.

According to equation (25), the analytical solution for the case of a partially-penetrating Gaussian source consists of two terms. The first term is the product of penetration ratio H/B, and the solution for the corresponding fully-penetrating case, c_f. The second term is Δc_p, which may be interpreted as a correction term that accounts for the effect of partial penetration.

STEADY-STATE ANALYTICAL SOLUTION

A steady-state condition may be approached by letting t approach infinity. Under this condition, the analytical solution given in (25) may be expressed as

$$c_p^*(x, y, z) = \frac{H}{B} c_f^*(x, y) + \Delta c_p^*(x, y, z) \tag{31}$$

where the asterisk superscript is used to denote the steady-state condition, and $c_f^*(x, y)$ and $\Delta c_p^*(x, y, z)$ are obtained from (26) and (27) with the upper limit of the time integral set to infinity.

An alternative steady-state analytical solution can also be obtained by direct solution of the steady-state advective-dispersive transport equation (equation (1) without the time-derivative term), subjected to the boundary conditions given by (2b)-(2g). This solution can be expressed in a concise form using equation (31) but with the function $c_f^*(x, y)$ and $\Delta c_p^*(x, y, z)$ defined as

$$c_f^*(x, y) = \xi' \int_{-\infty}^{\infty} \frac{\exp(-y'^2/2\sigma^2)}{\left\{x^2 + (y'-y)^2 D_x/D_y\right\}^{\frac{1}{2}}} K_1 \left\{ \left[\frac{\eta x^2}{D_x} + \frac{\eta (y'-y)^2}{D_y} \right]^{\frac{1}{2}} \right\} dy' \tag{32}$$

$$\Delta c_p^*(x, y, z) = \frac{2}{\pi} \sum_{n=1}^{\infty} \frac{1}{n} \sin(\frac{n\pi H}{B}) \cos(\frac{n\pi z}{B})$$

$$\xi' \int_{\infty}^{\infty} \frac{\exp(-y'/2\sigma^2)}{\left\{x^2 + (y'-y)^2 \, D_x/D_y\right\}^{\frac{1}{2}}}$$

$$\cdot \quad K_1 \left\{ \left[\frac{\beta_n x^2}{D_x} + \frac{\beta_n (y'-y)^2}{D_y} \right]^{\frac{1}{2}} \right\} dy' \qquad (33)$$

in which y' is a dummy variable of integration, ξ' is a constant defined as

$$\xi' = \frac{xc_o}{\pi} \sqrt{\frac{\beta_n}{D_y}} \exp(\frac{V_s x}{2D_x}) \qquad (34)$$

η and β_n are given by equations (29) and (30), and $K_1(\cdot)$ is the modified Bessel function of the second kind and of first order.

In a special case where one is interested in obtaining a steady-state concentration distribution along the x-axis, equation (31) becomes

$$c_p^*(x, 0, 0) = \frac{H}{B} c_f^*(x, 0) + \Delta c_p^*(x, 0, 0) \qquad (35)$$

where $c_f^*(x, 0)$ and $\Delta c_p^*(x, 0, 0)$ are obtained by reducing equations (32) and (33) to the following:

$$c_f^*(x,0) = \xi^* \int_0^{\infty} \exp \left\{ -\left[\frac{\sigma^2 \xi^2}{2} + x \sqrt{\frac{\xi^2 D_y}{D_x} + \frac{\eta}{D_x}} \right] \right\} d\xi \qquad (36)$$

$$\Delta c_p^*(x,0,0) = \frac{2}{\pi} \sum_{n=1}^{\infty} \frac{1}{n} \sin(\frac{n\pi H}{B}) \cos(\frac{n\pi z}{B})$$

$$\cdot \ \xi^* \int_0^{\infty} \exp \left\{ -\left[\frac{\sigma^2 \xi^2}{2} + x \sqrt{\frac{\xi^2 D_y}{D_x} + \frac{\beta_n}{D_x}} \right] \right\} d\xi \qquad (37)$$

with ξ* defined as

$$\xi^* = \frac{2c_o \sigma}{\sqrt{2\pi}} \exp \left\{ \frac{V_s x}{2D_x} \right\} \qquad (38)$$

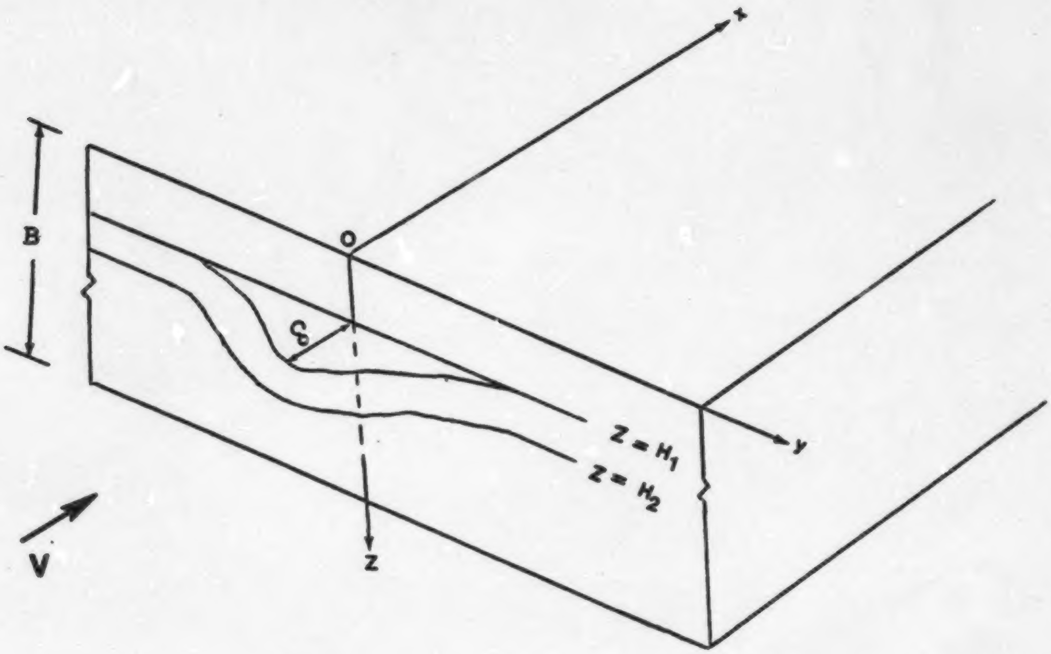

Figure 1.1. Schematic picture of the solution region with a contaminant source having concentration distribution that is Gaussian in the lateral direction and uniform between $H_1 \leq z \leq H_2$ in the vertical direction.

APPENDIX B

TABLES OF DIMENSIONLESS CONCENTRATION c_{fD}^{*} VERSUS x_D

```
TABLE  1:  XD VERSUS CD FOR SIGD =  0.500E 01

------------------------------------------------------------------------------------------------

             LAMD= 0.000E 00  LAMD= 0.400E-01  LAMD= 0.100E 00  LAMD= 0.200E 00  LAMD= 0.300E 00
  XD-VALUE      CD-VALUE         CD-VALUE         CD-VALUE         CD-VALUE         CD-VALUE

------------------------------------------------------------------------------------------------
 0.100E 01      0.981E 00        0.944E 00        0.893E 00        0.819E 00        0.756E 00
 0.150E 01      0.972E 00        0.935E 00        0.884E 00        0.808E 00        0.741E 00
 0.200E 01      0.963E 00        0.926E 00        0.875E 00        0.798E 00        0.731E 00
 0.300E 01      0.946E 00        0.910E 00        0.859E 00        0.782E 00        0.714E 00
 0.400E 01      0.930E 00        0.894E 00        0.844E 00        0.767E 00        0.699E 00
 0.500E 01      0.915E 00        0.879E 00        0.830E 00        0.754E 00        0.686E 00
 0.600E 01      0.900E 00        0.865E 00        0.816E 00        0.741E 00        0.674E 00
 0.700E 01      0.886E 00        0.852E 00        0.803E 00        0.730E 00        0.663E 00
 0.800E 01      0.873E 00        0.839E 00        0.791E 00        0.718E 00        0.653E 00
 0.900E 01      0.860E 00        0.827E 00        0.780E 00        0.707E 00        0.643E 00
 0.100E 02      0.848E 00        0.815E 00        0.768E 00        0.697E 00        0.633E 00
 0.150E 02      0.793E 00        0.763E 00        0.719E 00        0.652E 00        0.591E 00
 0.200E 02      0.748E 00        0.719E 00        0.678E 00        0.614E 00        0.557E 00

 0.250E 02      0.710E 00        0.682E 00        0.643E 00        0.583E 00        0.528E 00
 0.300E 02      0.677E 00        0.650E 00        0.613E 00        0.555E 00        0.503E 00
 0.400E 02      0.622E 00        0.598E 00        0.564E 00        0.511E 00        0.463E 00
 0.500E 02      0.579E 00        0.557E 00        0.525E 00        0.475E 00        0.430E 00
 0.600E 02      0.544E 00        0.523E 00        0.493E 00        0.446E 00        0.404E 00
 0.700E 02      0.514E 00        0.494E 00        0.466E 00        0.422E 00        0.392E 00
 0.800E 02      0.489E 00        0.470E 00        0.443E 00        0.401E 00        0.363E 00
 0.900E 02      0.467E 00        0.449E 00        0.423E 00        0.383E 00        0.347E 00
 0.100E 03      0.445E 00        0.431E 00        0.406E 00        0.367E 00        0.333E 00
 0.150E 03      0.379E 00        0.364E 00        0.343E 00        0.310E 00        0.281E 00
 0.200E 03      0.334E 00        0.321E 00        0.302E 00        0.273E 00        0.248E 00
 0.300E 03      0.278E 00        0.267E 00        0.251E 00        0.227E 00        0.206E 00
 0.400E 03      0.243E 00        0.233E 00        0.220E 00        0.199E 00        0.180E 00
 0.500E 03      0.218E 00        0.210E 00        0.198E 00        0.179E 00        0.152E 00
 0.600E 03      0.200E 00        0.192E 00        0.181E 00        0.164E 00        0.148E 00
 0.700E 03      0.186E 00        0.179E 00        0.168E 00        0.152E 00        0.138E 00
 0.800E 03      0.174E 00        0.167E 00        0.158E 00        0.143E 00        0.129E 00
 0.900E 03      0.164E 00        0.158E 00        0.149E 00        0.135E 00        0.122E 00
 0.100E 04      0.156E 00        0.150E 00        0.141E 00        0.129E 00        0.116E 00
------------------------------------------------------------------------------------------------
```

TABLE 2: XD VERSUS CD FOR SIGD = 0.500E 01

XD-VALUE	LAMD= 0.400E 00 CD-VALUE	LAMD= 0.600E 00 CD-VALUE	LAMD= 0.800E 00 CD-VALUE	LAMD= 0.100E 01 CD-VALUE	LAMD= 0.120E 01 CD-VALUE
0.100E 01	0.700E 00	0.609E 00	0.535E 00	0.476E 00	0.425E 00
0.150E 01	0.683E 00	0.586E 00	0.508E 00	0.445E 00	0.392E 00
0.200E 01	0.671E 00	0.571E 00	0.491E 00	0.425E 00	0.371E 00
0.300E 01	0.653E 00	0.550E 00	0.468E 00	0.400E 00	0.344E 00
0.400E 01	0.638E 00	0.535E 00	0.451E 00	0.383E 00	0.327E 00
0.500E 01	0.626E 00	0.523E 00	0.439E 00	0.370E 00	0.314E 00
0.600E 01	0.614E 00	0.512E 00	0.428E 00	0.360E 00	0.304E 00
0.700E 01	0.604E 00	0.502E 00	0.419E 00	0.351E 00	0.296E 00
0.800E 01	0.594E 00	0.493E 00	0.411E 00	0.344E 00	0.288E 00
0.900E 01	0.584E 00	0.485E 00	0.403E 00	0.337E 00	0.282E 00
0.100E 02	0.576E 00	0.477E 00	0.396E 00	0.330E 00	0.276E 00
0.150E 02	0.537E 00	0.443E 00	0.367E 00	0.304E 00	0.253E 00
0.200E 02	0.506E 00	0.417E 00	0.344E 00	0.285E 00	0.236E 00
0.250E 02	0.479E 00	0.394E 00	0.325E 00	0.269E 00	0.222E 00
0.300E 02	0.456E 00	0.375E 00	0.309E 00	0.255E 00	0.211E 00
0.400E 02	0.419E 00	0.345E 00	0.284E 00	0.233E 00	0.192E 00
0.500E 02	0.390E 00	0.320E 00	0.263E 00	0.217E 00	0.178E 00
0.600E 02	0.366E 00	0.300E 00	0.247E 00	0.203E 00	0.167E 00
0.700E 02	0.346E 00	0.284E 00	0.233E 00	0.192E 00	0.157E 00
0.800E 02	0.329E 00	0.270E 00	0.222E 00	0.182E 00	0.150E 00
0.900E 02	0.314E 00	0.258E 00	0.211E 00	0.174E 00	0.143E 00
0.100E 03	0.301E 00	0.247E 00	0.203E 00	0.166E 00	0.137E 00
0.150E 03	0.254E 00	0.208E 00	0.171E 00	0.140E 00	0.115E 00
0.200E 03	0.224E 00	0.184E 00	0.151E 00	0.123E 00	0.101E 00
0.300E 03	0.186E 00	0.153E 00	0.125E 00	0.102E 00	0.840E-01
0.400E 03	0.163E 00	0.133E 00	0.109E 00	0.895E-01	0.733E-01
0.500E 03	0.146E 00	0.120E 00	0.983E-01	0.805E-01	0.659E-01
0.600E 03	0.134E 00	0.110E 00	0.900E-01	0.737E-01	0.604E-01
0.700E 03	0.125E 00	0.102E 00	0.836E-01	0.684E-01	0.561E-01
0.800E 03	0.117E 00	0.956E-01	0.783E-01	0.641E-01	0.525E-01
0.900E 03	0.110E 00	0.903E-01	0.740E-01	0.606E-01	0.496E-01
0.100E 04	0.105E 00	0.858E-01	0.702E-01	0.575E-01	0.471E-01

TABLE 3: XD VERSUS CD FOR SIGD = 0.500E 01

```
-----------------------------------------------------------------------------------------------
             LAMD= 0.140E 01  LAMD= 0.160E 01  LAMD= 0.180E 01  LAMD= 0.200E 01  LAMD= 0.250E 01
 XD-VALUE       CD-VALUE         CD-VALUE         CD-VALUE         CD-VALUE         CD-VALUE

-----------------------------------------------------------------------------------------------
0.100E 01      0.383E 00        0.347E 00        0.315E 00        0.288E 00        0.233E 00
0.150E 01      0.348E 00        0.310E 00        0.278E 00        0.250E 00        0.195E 00
0.200E 01      0.325E 00        0.287E 00        0.254E 00        0.226E 00        0.172E 00
0.300E 01      0.298E 00        0.259E 00        0.226E 00        0.198E 00        0.145E 00
0.400E 01      0.280E 00        0.241E 00        0.208E 00        0.181E 00        0.129E 00
0.500E 01      0.268E 00        0.229E 00        0.196E 00        0.169E 00        0.118E 00
0.600E 01      0.258E 00        0.219E 00        0.187E 00        0.160E 00        0.110E 00
0.700E 01      0.250E 00        0.212E 00        0.180E 00        0.153E 00        0.104E 00
0.800E 01      0.243E 00        0.205E 00        0.174E 00        0.148E 00        0.994E-01
0.900E 01      0.237E 00        0.200E 00        0.169E 00        0.143E 00        0.954E-01
0.100E 02      0.232E 00        0.195E 00        0.164E 00        0.139E 00        0.919E-01
0.150E 02      0.211E 00        0.176E 00        0.147E 00        0.123E 00        0.799E-01
0.200E 02      0.196E 00        0.163E 00        0.136E 00        0.113E 00        0.722E-01
0.250E 02      0.184E 00        0.153E 00        0.127E 00        0.105E 00        0.667E-01
0.300E 02      0.174E 00        0.144E 00        0.119E 00        0.991E-01        0.624E-01
0.400E 02      0.159E 00        0.131E 00        0.108E 00        0.896E-01        0.560E-01
0.500E 02      0.147E 00        0.121E 00        0.999E-01        0.825E-01        0.513E-01
0.600E 02      0.137E 00        0.113E 00        0.932E-01        0.769E-01        0.476E-01
0.700E 02      0.130E 00        0.107E 00        0.878E-01        0.723E-01        0.446E-01
0.800E 02      0.123E 00        0.101E 00        0.832E-01        0.685E-01        0.422E-01
0.900E 02      0.117E 00        0.964E-01        0.792E-01        0.652E-01        0.401E-01
0.100E 03      0.112E 00        0.922E-01        0.758E-01        0.624E-01        0.383E-01
0.150E 03      0.944E-01        0.774E-01        0.636E-01        0.522E-01        0.319E-01
0.200E 03      0.830E-01        0.681E-01        0.558E-01        0.458E-01        0.280E-01
0.300E 03      0.688E-01        0.564E-01        0.463E-01        0.379E-01        0.231E-01
0.400E 03      0.601E-01        0.493E-01        0.404E-01        0.331E-01        0.201E-01
0.500E 03      0.540E-01        0.443E-01        0.363E-01        0.297E-01        0.181E-01
0.600E 03      0.495E-01        0.405E-01        0.332E-01        0.272E-01        0.165E-01
0.700E 03      0.459E-01        0.376E-01        0.308E-01        0.253E-01        0.153E-01
0.800E 03      0.430E-01        0.353E-01        0.289E-01        0.237E-01        0.144E-01
0.900E 03      0.406E-01        0.333E-01        0.273E-01        0.223E-01        0.136E-01
0.100E 04      0.386E-01        0.316E-01        0.259E-01        0.212E-01        0.129E-01
-----------------------------------------------------------------------------------------------
```

TABLE 4: XD VERSUS CD FOR SIGD = 0.500E 01

XD-VALUE	LAMD= 0.300E 01 CD-VALUE	LAMD= 0.400E 01 CD-VALUE	LAMD= 0.600E 01 CD-VALUE	LAMD= 0.800E 01 CD-VALUE	LAMD= 0.100E 02 CD-VALUE
0.100E 01	0.191E 00	0.134E 00	0.735E-01	0.438E-01	0.277E-01
0.150E 01	0.155E 00	0.102E 00	0.493E-01	0.265E-01	0.152E-01
0.200E 01	0.133E 00	0.829E-01	0.367E-01	0.181E-01	0.961E-02
0.300E 01	0.108E 00	0.624E-01	0.239E-01	0.103E-01	0.485E-02
0.400E 01	0.933E-01	0.512E-01	0.176E-01	0.688E-02	0.294E-02
0.500E 01	0.838E-01	0.441E-01	0.140E-01	0.503E-02	0.198E-02
0.600E 01	0.771E-01	0.393E-01	0.116E-01	0.390E-02	0.144E-02
0.700E 01	0.720E-01	0.357E-01	0.995E-02	0.315E-02	0.110E-02
0.800E 01	0.679E-01	0.329E-01	0.873E-02	0.263E-02	0.872E-03
0.900E 01	0.645E-01	0.307E-01	0.781E-02	0.225E-02	0.713E-03
0.100E 02	0.617E-01	0.289E-01	0.708E-02	0.196E-02	0.597E-03
0.150E 02	0.523E-01	0.231E-01	0.495E-02	0.119E-02	0.311E-03
0.200E 02	0.466E-01	0.198E-01	0.392E-02	0.855E-03	0.202E-03
0.250E 02	0.426E-01	0.177E-01	0.331E-02	0.674E-03	0.148E-03
0.300E 02	0.396E-01	0.162E-01	0.290E-02	0.562E-03	0.117E-03
0.400E 02	0.351E-01	0.141E-01	0.238E-02	0.429E-03	0.823E-04
0.500E 02	0.320E-01	0.126E-01	0.205E-02	0.354E-03	0.642E-04
0.600E 02	0.296E-01	0.115E-01	0.183E-02	0.305E-03	0.532E-04
0.700E 02	0.277E-01	0.107E-01	0.166E-02	0.270E-03	0.458E-04
0.800E 02	0.261E-01	0.100E-01	0.154E-02	0.244E-03	0.404E-04
0.900E 02	0.247E-01	0.948E-02	0.143E-02	0.224E-03	0.364E-04
0.100E 03	0.236E-01	0.900E-02	0.135E-02	0.208E-03	0.333E-04
0.150E 03	0.196E-01	0.739E-02	0.107E-02	0.159E-03	0.241E-04
0.200E 03	0.171E-01	0.641E-02	0.915E-03	0.133E-03	0.196E-04
0.300E 03	0.141E-01	0.525E-02	0.737E-03	0.105E-03	0.150E-04
0.400E 03	0.123E-01	0.456E-02	0.633E-03	0.889E-04	0.126E-04
0.500E 03	0.110E-01	0.408E-02	0.564E-03	0.786E-04	0.110E-04
0.600E 03	0.101E-01	0.373E-02	0.513E-03	0.712E-04	0.994E-05
0.700E 03	0.933E-02	0.345E-02	0.474E-03	0.656E-04	0.911E-05
0.800E 03	0.874E-02	0.323E-02	0.443E-03	0.611E-04	0.846E-05
0.900E 03	0.824E-02	0.305E-02	0.417E-03	0.574E-04	0.793E-05
0.100E 04	0.782E-02	0.289E-02	0.395E-03	0.543E-04	0.749E-05

TABLE 5: XD VERSUS CD FOR SIGD = 0.100E 02

XD-VALUE	LAMD= 0.000E 00 CD-VALUE	LAMD= 0.400E-01 CD-VALUE	LAMD= 0.100E 00 CD-VALUE	LAMD= 0.200E 00 CD-VALUE	LAMD= 0.300E 00 CD-VALUE
0.100E 01	0.995E 00	0.957E 00	0.905E 00	0.829E 00	0.764E 00
0.150E 01	0.993E 00	0.954E 00	0.901E 00	0.823E 00	0.755E 00
0.200E 01	0.990E 00	0.952E 00	0.899E 00	0.819E 00	0.749E 00
0.300E 01	0.985E 00	0.947E 00	0.893E 00	0.813E 00	0.741E 00
0.400E 01	0.981E 00	0.943E 00	0.889E 00	0.807E 00	0.735E 00
0.500E 01	0.976E 00	0.938E 00	0.884E 00	0.803E 00	0.730E 00
0.600E 01	0.971E 00	0.934E 00	0.880E 00	0.799E 00	0.726E 00
0.700E 01	0.967E 00	0.929E 00	0.876E 00	0.795E 00	0.722E 00
0.800E 01	0.962E 00	0.925E 00	0.872E 00	0.791E 00	0.718E 00
0.900E 01	0.958E 00	0.921E 00	0.868E 00	0.787E 00	0.714E 00
0.100E 02	0.954E 00	0.917E 00	0.864E 00	0.783E 00	0.711E 00
0.150E 02	0.933E 00	0.897E 00	0.845E 00	0.765E 00	0.694E 00
0.200E 02	0.913E 00	0.878E 00	0.827E 00	0.749E 00	0.679E 00
0.250E 02	0.895E 00	0.860E 00	0.810E 00	0.734E 00	0.665E 00
0.300E 02	0.878E 00	0.843E 00	0.795E 00	0.720E 00	0.652E 00
0.400E 02	0.846E 00	0.813E 00	0.766E 00	0.693E 00	0.628E 00
0.500E 02	0.817E 00	0.785E 00	0.740E 00	0.670E 00	0.607E 00
0.600E 02	0.791E 00	0.760E 00	0.716E 00	0.648E 00	0.587E 00
0.700E 02	0.768E 00	0.738E 00	0.695E 00	0.629E 00	0.570E 00
0.800E 02	0.746E 00	0.717E 00	0.675E 00	0.611E 00	0.553E 00
0.900E 02	0.726E 00	0.698E 00	0.657E 00	0.595E 00	0.539E 00
0.100E 03	0.708E 00	0.680E 00	0.641E 00	0.580E 00	0.525E 00
0.150E 03	0.633E 00	0.608E 00	0.573E 00	0.519E 00	0.469E 00
0.200E 03	0.578E 00	0.555E 00	0.523E 00	0.473E 00	0.428E 00
0.300E 03	0.500E 00	0.481E 00	0.453E 00	0.410E 00	0.371E 00
0.400E 03	0.447E 00	0.430E 00	0.405E 00	0.366E 00	0.332E 00
0.500E 03	0.408E 00	0.392E 00	0.370E 00	0.334E 00	0.303E 00
0.600E 03	0.378E 00	0.363E 00	0.342E 00	0.310E 00	0.280E 00
0.700E 03	0.354E 00	0.340E 00	0.320E 00	0.290E 00	0.262E 00
0.800E 03	0.333E 00	0.320E 00	0.302E 00	0.273E 00	0.247E 00
0.900E 03	0.316E 00	0.304E 00	0.286E 00	0.259E 00	0.234E 00
0.100E 04	0.302E 00	0.290E 00	0.273E 00	0.247E 00	0.223E 00

TABLE 6: XD VERSUS CD FOR SIGD = 0.100E 02

XD-VALUE	LAMD= 0.400E 00 CD-VALUE	LAMD= 0.600E 00 CD-VALUE	LAMD= 0.800E 00 CD-VALUE	LAMD= 0.100E 01 CD-VALUE	LAMD= 0.120E 01 CD-VALUE
0.100E 01	0.708E 00	0.615E 00	0.540E 00	0.480E 00	0.429E 00
0.150E 01	0.695E 00	0.596E 00	0.516E 00	0.451E 00	0.397E 00
0.200E 01	0.687E 00	0.584E 00	0.501E 00	0.434E 00	0.378E 00
0.300E 01	0.677E 00	0.570E 00	0.483E 00	0.413E 00	0.355E 00
0.400E 01	0.671E 00	0.561E 00	0.473E 00	0.401E 00	0.341E 00
0.500E 01	0.665E 00	0.555E 00	0.465E 00	0.392E 00	0.332E 00
0.600E 01	0.661E 00	0.549E 00	0.459E 00	0.385E 00	0.325E 00
0.700E 01	0.656E 00	0.545E 00	0.454E 00	0.380E 00	0.320E 00
0.800E 01	0.652E 00	0.541E 00	0.450E 00	0.376E 00	0.315E 00
0.900E 01	0.649E 00	0.537E 00	0.446E 00	0.372E 00	0.311E 00
0.100E 02	0.645E 00	0.534E 00	0.443E 00	0.369E 00	0.308E 00
0.150E 02	0.630E 00	0.519E 00	0.429E 00	0.355E 00	0.295E 00
0.200E 02	0.616E 00	0.507E 00	0.418E 00	0.345E 00	0.286E 00
0.250E 02	0.603E 00	0.496E 00	0.408E 00	0.337E 00	0.278E 00
0.300E 02	0.591E 00	0.486E 00	0.400E 00	0.329E 00	0.272E 00
0.400E 02	0.569E 00	0.467E 00	0.384E 00	0.316E 00	0.260E 00
0.500E 02	0.549E 00	0.451E 00	0.370E 00	0.305E 00	0.251E 00
0.600E 02	0.532E 00	0.436E 00	0.358E 00	0.294E 00	0.242E 00
0.700E 02	0.516E 00	0.423E 00	0.347E 00	0.285E 00	0.234E 00
0.800E 02	0.501E 00	0.411E 00	0.337E 00	0.277E 00	0.227E 00
0.900E 02	0.488E 00	0.400E 00	0.328E 00	0.269E 00	0.221E 00
0.100E 03	0.475E 00	0.390E 00	0.320E 00	0.262E 00	0.215E 00
0.150E 03	0.425E 00	0.348E 00	0.285E 00	0.234E 00	0.192E 00
0.200E 03	0.388E 00	0.318E 00	0.260E 00	0.213E 00	0.175E 00
0.300E 03	0.336E 00	0.275E 00	0.225E 00	0.185E 00	0.151E 00
0.400E 03	0.300E 00	0.246E 00	0.201E 00	0.165E 00	0.135E 00
0.500E 03	0.274E 00	0.224E 00	0.184E 00	0.151E 00	0.123E 00
0.600E 03	0.254E 00	0.208E 00	0.170E 00	0.139E 00	0.114E 00
0.700E 03	0.237E 00	0.194E 00	0.159E 00	0.130E 00	0.107E 00
0.800E 03	0.224E 00	0.183E 00	0.150E 00	0.123E 00	0.101E 00
0.900E 03	0.212E 00	0.174E 00	0.142E 00	0.116E 00	0.954E-01
0.100E 04	0.202E 00	0.166E 00	0.136E 00	0.111E 00	0.910E-01

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TABLE  7:  XD VERSUS CD FOR SIGD =  0.100E 02
---------------------------------------------------------------------------------------------------
                LAMD= 0.140E 01  LAMD= 0.160E 01  LAMD= 0.180E 01  LAMD= 0.200E 01  LAMD= 0.250E 01
   XD-VALUE        CD-VALUE         CD-VALUE         CD-VALUE         CD-VALUE         CD-VALUE
---------------------------------------------------------------------------------------------------
  0.100E 01       0.386E 00        0.349E 00        0.318E 00        0.290E 00        0.234E 00
  0.150E 01       0.352E 00        0.314E 00        0.281E 00        0.253E 00        0.197E 00
  0.200E 01       0.331E 00        0.292E 00        0.259E 00        0.230E 00        0.174E 00
  0.300E 01       0.307E 00        0.266E 00        0.232E 00        0.203E 00        0.148E 00
  0.400E 01       0.292E 00        0.251E 00        0.217E 00        0.185E 00        0.134E 00
  0.500E 01       0.282E 00        0.241E 00        0.207E 00        0.178E 00        0.124E 00
  0.600E 01       0.275E 00        0.234E 00        0.199E 00        0.171E 00        0.117E 00
  0.700E 01       0.270E 00        0.228E 00        0.194E 00        0.165E 00        0.112E 00
  0.800E 01       0.265E 00        0.224E 00        0.189E 00        0.161E 00        0.108E 00
  0.900E 01       0.261E 00        0.220E 00        0.185E 00        0.157E 00        0.104E 00
  0.100E 02       0.258E 00        0.216E 00        0.182E 00        0.154E 00        0.102E 00
  0.150E 02       0.246E 00        0.205E 00        0.171E 00        0.143E 00        0.924E-01
  0.200E 02       0.237E 00        0.197E 00        0.164E 00        0.136E 00        0.569E-01
  0.250E 02       0.230E 00        0.191E 00        0.158E 00        0.131E 00        0.830E-01
  0.300E 02       0.224E 00        0.186E 00        0.154E 00        0.127E 00        0.800E-01
  0.400E 02       0.215E 00        0.177E 00        0.146E 00        0.121E 00        0.753E-01
  0.500E 02       0.206E 00        0.170E 00        0.140E 00        0.116E 00        0.717E-01
  0.500E 02       0.199E 00        0.164E 00        0.135E 00        0.111E 00        0.688E-01
  0.700E 02       0.193E 00        0.158E 00        0.130E 00        0.107E 00        0.662E-01
  0.800E 02       0.187E 00        0.154E 00        0.126E 00        0.104E 00        0.640E-01
  0.900E 02       0.182E 00        0.149E 00        0.123E 00        0.101E 00        0.620E-01
  0.100E 03       0.177E 00        0.145E 00        0.119E 00        0.982E-01        0.603E-01
  0.150E 03       0.158E 00        0.129E 00        0.106E 00        0.871E-01        0.533E-01
  0.200E 03       0.144E 00        0.118E 00        0.966E-01        0.792E-01        0.454E-01
  0.300E 03       0.124E 00        0.102E 00        0.833E-01        0.683E-01        0.416E-01
  0.400E 03       0.111E 00        0.908E-01        0.744E-01        0.610E-01        0.371E-01
  0.500E 03       0.101E 00        0.825E-01        0.678E-01        0.556E-01        0.338E-01
  0.500E 03       0.935E-01        0.766E-01        0.628E-01        0.514E-01        0.313E-01
  0.700E 03       0.874E-01        0.716E-01        0.587E-01        0.481E-01        0.292E-01
  0.800E 03       0.824E-01        0.675E-01        0.553E-01        0.453E-01        0.275E-01
  0.900E 03       0.781E-01        0.640E-01        0.524E-01        0.429E-01        0.251E-01
  0.100E 04       0.745E-01        0.610E-01        0.500E-01        0.409E-01        0.249E-01
---------------------------------------------------------------------------------------------------
```

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TABLE 8: XD VERSUS CD FOR SIGD = 0.100E 02

XD-VALUE	LAMD= 0.300E 01 CD-VALUE	LAMD= 0.400E 01 CD-VALUE	LAMD= 0.600E 01 CD-VALUE	LAMD= 0.800E 01 CD-VALUE	LAMD= 0.100E 02 CD-VALUE
0.100E 01	0.193E 00	0.135E 00	0.738E-01	0.440E-01	0.278E-01
0.150E 01	0.156E 00	0.103E 00	0.497E-01	0.266E-01	0.153E-01
0.200E 01	0.135E 00	0.840E-01	0.371E-01	0.183E-01	0.959E-02
0.300E 01	0.110E 00	0.638E-01	0.244E-01	0.105E-01	0.493E-02
0.400E 01	0.966E-01	0.529E-01	0.181E-01	0.706E-02	0.301E-02
0.500E 01	0.878E-01	0.461E-01	0.145E-01	0.520E-02	0.205E-02
0.600E 01	0.816E-01	0.414E-01	0.122E-01	0.407E-02	0.150E-02
0.700E 01	0.770E-01	0.380E-01	0.105E-01	0.332E-02	0.115E-02
0.800E 01	0.734E-01	0.354E-01	0.934E-02	0.280E-02	0.923E-03
0.900E 01	0.705E-01	0.333E-01	0.843E-02	0.241E-02	0.762E-03
0.100E 02	0.681E-01	0.317E-01	0.771E-02	0.212E-02	0.544E-03
0.150E 02	0.603E-01	0.265E-01	0.564E-02	0.134E-02	0.349E-03
0.200E 02	0.559E-01	0.237E-01	0.465E-02	0.101E-02	0.236E-03
0.250E 02	0.529E-01	0.219E-01	0.406E-02	0.821E-03	0.179E-03
0.300E 02	0.506E-01	0.206E-01	0.366E-02	0.70[illegible]-03	0.146E-03
0.400E 02	0.472E-01	0.188E-01	0.316E-02	0.566E-03	0.108E-03
0.500E 02	0.447E-01	0.176E-01	0.284E-02	0.488E-03	0.881E-04
0.600E 02	0.427E-01	0.166E-01	0.262E-02	0.435E-03	0.756E-04
0.700E 02	0.410E-01	0.158E-01	0.245E-02	0.397E-03	0.669E-04
0.800E 02	0.395E-01	0.152E-01	0.232E-02	0.367E-03	0.606E-04
0.900E 02	0.382E-01	0.146E-01	0.220E-02	0.344E-03	0.557E-04
0.100E 03	0.371E-01	0.141E-01	0.211E-02	0.325E-03	0.518E-04
0.150E 03	0.326E-01	0.123E-01	0.178E-02	0.264E-03	0.400E-04
0.200E 03	0.296E-01	0.111E-01	0.158E-02	0.229E-03	0.338E-04
0.300E 03	0.254E-01	0.945E-02	0.133E-02	0.188E-03	0.270E-04
0.400E 03	0.226E-01	0.839E-02	0.117E-02	0.164E-03	0.232E-04
0.500E 03	0.206E-01	0.763E-02	0.105E-02	0.147E-03	0.206E-04
0.600E 03	0.190E-01	0.704E-02	0.970E-03	0.134E-03	0.188E-04
0.700E 03	0.178E-01	0.657E-02	0.903E-03	0.125E-03	0.173E-04
0.800E 03	0.167E-01	0.618E-02	0.848E-03	0.117E-03	0.162E-04
0.900E 03	0.159E-01	0.586E-02	0.802E-03	0.110E-03	0.152E-04
0.100E 04	0.151E-01	0.558E-02	0.763E-03	0.105E-03	0.145E-04

TABLE 9: XD VERSUS CD FOR SIGD = 0.150E 02

XD-VALUE	LAMD= 0.000E 00 CD-VALUE	LAMD= 0.400E-01 CD-VALUE	LAMD= 0.100E 00 CD-VALUE	LAMD= 0.200E 00 CD-VALUE	LAMD= 0.300E 00 CD-VALUE
0.100E 01	0.998E 00	0.959E 00	0.907E 00	0.831E 00	0.766E 00
0.150E 01	0.997E 00	0.958E 00	0.905E 00	0.826E 00	0.758E 00
0.200E 01	0.996E 00	0.957E 00	0.903E 00	0.823E 00	0.753E 00
0.300E 01	0.993E 00	0.955E 00	0.901E 00	0.819E 00	0.746E 00
0.400E 01	0.991E 00	0.953E 00	0.898E 00	0.816E 00	0.743E 00
0.500E 01	0.989E 00	0.951E 00	0.896E 00	0.813E 00	0.739E 00
0.600E 01	0.987E 00	0.948E 00	0.894E 00	0.811E 00	0.737E 00
0.700E 01	0.985E 00	0.946E 00	0.892E 00	0.809E 00	0.735E 00
0.800E 01	0.983E 00	0.944E 00	0.890E 00	0.807E 00	0.732E 00
0.900E 01	0.981E 00	0.942E 00	0.888E 00	0.805E 00	0.730E 00
0.100E 02	0.979E 00	0.940E 00	0.886E 00	0.803E 00	0.729E 00
0.150E 02	0.968E 00	0.930E 00	0.877E 00	0.794E 00	0.720E 00
0.200E 02	0.958E 00	0.921E 00	0.868E 00	0.786E 00	0.712E 00
0.250E 02	0.949E 00	0.912E 00	0.859E 00	0.778E 00	0.705E 00
0.300E 02	0.939E 00	0.903E 00	0.850E 00	0.770E 00	0.697E 00
0.400E 02	0.922E 00	0.886E 00	0.834E 00	0.755E 00	0.684E 00
0.500E 02	0.905E 00	0.869E 00	0.819E 00	0.741E 00	0.671E 00
0.600E 02	0.889E 00	0.854E 00	0.804E 00	0.728E 00	0.659E 00
0.700E 02	0.874E 00	0.839E 00	0.791E 00	0.716E 00	0.648E 00
0.800E 02	0.859E 00	0.826E 00	0.778E 00	0.704E 00	0.637E 00
0.900E 02	0.845E 00	0.812E 00	0.765E 00	0.693E 00	0.627E 00
0.100E 03	0.832E 00	0.800E 00	0.753E 00	0.682E 00	0.617E 00
0.150E 03	0.775E 00	0.745E 00	0.701E 00	0.635E 00	0.574E 00
0.200E 03	0.728E 00	0.699E 00	0.659E 00	0.576E 00	0.540E 00
0.300E 03	0.655E 00	0.629E 00	0.593E 00	0.536E 00	0.485E 00
0.400E 03	0.600E 00	0.577E 00	0.543E 00	0.492E 00	0.445E 00
0.500E 03	0.557E 00	0.535E 00	0.504E 00	0.456E 00	0.413E 00
0.600E 03	0.522E 00	0.502E 00	0.473E 00	0.429E 00	0.387E 00
0.700E 03	0.493E 00	0.474E 00	0.446E 00	0.404E 00	0.366E 00
0.800E 03	0.469E 00	0.450E 00	0.424E 00	0.384E 00	0.347E 00
0.900E 03	0.447E 00	0.430E 00	0.405E 00	0.366E 00	0.331E 00
0.100E 04	0.429E 00	0.412E 00	0.388E 00	0.351E 00	0.318E 00

TABLE 10: XD VERSUS CD FOR SIGD = 0.150E 02

XD-VALUE	LAMD= 0.400E 00 CD-VALUE	LAMD= 0.600E 00 CD-VALUE	LAMD= 0.800E 00 CD-VALUE	LAMD= 0.100E 01 CD-VALUE	LAMD= 0.120E 01 CD-VALUE
0.100E 01	0.709E 00	0.616E 00	0.541E 00	0.480E 00	0.430E 00
0.150E 01	0.698E 00	0.598E 00	0.518E 00	0.452E 00	0.398E 00
0.200E 01	0.691E 00	0.587E 00	0.503E 00	0.435E 00	0.379E 00
0.300E 01	0.682E 00	0.574E 00	0.487E 00	0.416E 00	0.357E 00
0.400E 01	0.677E 00	0.566E 00	0.477E 00	0.404E 00	0.344E 00
0.500E 01	0.673E 00	0.561E 00	0.470E 00	0.396E 00	0.336E 00
0.600E 01	0.670E 00	0.557E 00	0.466E 00	0.391E 00	0.329E 00
0.700E 01	0.668E 00	0.554E 00	0.462E 00	0.386E 00	0.325E 00
0.800E 01	0.665E 00	0.551E 00	0.459E 00	0.383E 00	0.321E 00
0.900E 01	0.663E 00	0.549E 00	0.456E 00	0.380E 00	0.318E 00
0.100E 02	0.662E 00	0.547E 00	0.454E 00	0.377E 00	0.315E 00
0.150E 02	0.653E 00	0.538E 00	0.445E 00	0.369E 00	0.306E 00
0.200E 02	0.645E 00	0.531E 00	0.438E 00	0.362E 00	0.299E 00
0.250E 02	0.639E 00	0.525E 00	0.432E 00	0.357E 00	0.294E 00
0.300E 02	0.632E 00	0.519E 00	0.427E 00	0.352E 00	0.290E 00
0.400E 02	0.619E 00	0.509E 00	0.418E 00	0.344E 00	0.283E 00
0.500E 02	0.608E 00	0.499E 00	0.410E 00	0.337E 00	0.277E 00
0.600E 02	0.597E 00	0.490E 00	0.402E 00	0.330E 00	0.271E 00
0.700E 02	0.587E 00	0.481E 00	0.395E 00	0.324E 00	0.266E 00
0.800E 02	0.577E 00	0.473E 00	0.388E 00	0.319E 00	0.262E 00
0.900E 02	0.568E 00	0.465E 00	0.382E 00	0.313E 00	0.257E 00
0.100E 03	0.559E 00	0.458E 00	0.376E 00	0.309E 00	0.253E 00
0.150E 03	0.520E 00	0.426E 00	0.349E 00	0.286E 00	0.235E 00
0.200E 03	0.488E 00	0.400E 00	0.328E 00	0.269E 00	0.220E 00
0.300E 03	0.439E 00	0.360E 00	0.295E 00	0.242E 00	0.198E 00
0.400E 03	0.403E 00	0.330E 00	0.270E 00	0.221E 00	0.181E 00
0.500E 03	0.374E 00	0.306E 00	0.251E 00	0.205E 00	0.168E 00
0.600E 03	0.350E 00	0.287E 00	0.235E 00	0.192E 00	0.158E 00
0.700E 03	0.331E 00	0.271E 00	0.222E 00	0.182E 00	0.149E 00
0.800E 03	0.314E 00	0.257E 00	0.211E 00	0.173E 00	0.141E 00
0.900E 03	0.300E 00	0.246E 00	0.201E 00	0.165E 00	0.135E 00
0.100E 04	0.287E 00	0.235E 00	0.193E 00	0.158E 00	0.129E 00

TABLE 11: XD VERSUS CD FOR SIGD = 0.150E 02

XD-VALUE	LAMD= 0.140E 01 CD-VALUE	LAMD= 0.160E 01 CD-VALUE	LAMD= 0.180E 01 CD-VALUE	LAMD= 0.200E 01 CD-VALUE	LAMD= 0.250E 01 CD-VALUE
0.100E 01	0.387E 00	0.350E 00	0.318E 00	0.290E 00	0.234E 00
0.150E 01	0.353E 00	0.314E 00	0.281E 00	0.253E 00	0.197E 00
0.200E 01	0.332E 00	0.293E 00	0.259E 00	0.231E 00	0.175E 00
0.300E 01	0.308E 00	0.268E 00	0.234E 00	0.205E 00	0.149E 00
0.400E 01	0.295E 00	0.253E 00	0.219E 00	0.190E 00	0.135E 00
0.500E 01	0.285E 00	0.244E 00	0.209E 00	0.180E 00	0.125E 00
0.600E 01	0.279E 00	0.237E 00	0.202E 00	0.173E 00	0.118E 00
0.700E 01	0.274E 00	0.232E 00	0.197E 00	0.167E 00	0.113E 00
0.800E 01	0.270E 00	0.228E 00	0.192E 00	0.163E 00	0.110E 00
0.900E 01	0.266E 00	0.224E 00	0.189E 00	0.160E 00	0.106E 00
0.100E 02	0.264E 00	0.221E 00	0.186E 00	0.157E 00	0.104E 00
0.150E 02	0.254E 00	0.212E 00	0.177E 00	0.148E 00	0.955E-01
0.200E 02	0.248E 00	0.206E 00	0.171E 00	0.143E 00	0.908E-01
0.250E 02	0.243E 00	0.202E 00	0.167E 00	0.139E 00	0.877E-01
0.300E 02	0.240E 00	0.198E 00	0.164E 00	0.136E 00	0.853E-01
0.400E 02	0.233E 00	0.192E 00	0.159E 00	0.131E 00	0.818E-01
0.500E 02	0.228E 00	0.188E 00	0.155E 00	0.128E 00	0.792E-01
0.600E 02	0.223E 00	0.184E 00	0.151E 00	0.125E 00	0.770E-01
0.700E 02	0.219E 00	0.180E 00	0.148E 00	0.122E 00	0.752E-01
0.800E 02	0.215E 00	0.177E 00	0.145E 00	0.120E 00	0.735E-01
0.900E 02	0.211E 00	0.174E 00	0.143E 00	0.117E 00	0.721E-01
0.100E 03	0.208E 00	0.171E 00	0.140E 00	0.115E 00	0.707E-01
0.150E 03	0.193E 00	0.158E 00	0.130E 00	0.107E 00	0.651E-01
0.200E 03	0.181E 00	0.148E 00	0.122E 00	0.997E-01	0.609E-01
0.300E 03	0.162E 00	0.133E 00	0.109E 00	0.894E-01	0.544E-01
0.400E 03	0.149E 00	0.122E 00	0.998E-01	0.815E-01	0.498E-01
0.500E 03	0.138E 00	0.113E 00	0.925E-01	0.758E-01	0.461E-01
0.600E 03	0.129E 00	0.106E 00	0.867E-01	0.710E-01	0.432E-01
0.700E 03	0.122E 00	0.999E-01	0.818E-01	0.670E-01	0.407E-01
0.800E 03	0.116E 00	0.948E-01	0.777E-01	0.636E-01	0.387E-01
0.900E 03	0.110E 00	0.905E-01	0.741E-01	0.607E-01	0.369E-01
0.100E 04	0.106E 00	0.867E-01	0.710E-01	0.582E-01	0.353E-01

TABLE 12: XD VERSUS CD FOR SIGD = 0.150E 02

```
------------------------------------------------------------------------------------------
            LAMD= 0.300E 01  LAMD= 0.400E 01  LAMD= 0.600E 01  LAMD= 0.800E 01  LAMD= 0.100E 02
  XD-VALUE     CD-VALUE         CD-VALUE         CD-VALUE         CD-VALUE         CD-VALUE
------------------------------------------------------------------------------------------
 0.100E 01    0.193E 00        0.135E 00        0.738E-01        0.440E-01        0.278E-01
 0.150E 01    0.156E 00        0.103E 00        0.497E-01        0.267E-01        0.153E-01
 0.200E 01    0.135E 00        0.942E-01        0.371E-01        0.183E-01        0.971E-02
 0.300E 01    0.111E 00        0.641E-01        0.244E-01        0.105E-01        0.495E-02
 0.400E 01    0.973E-01        0.532E-01        0.182E-01        0.710E-02        0.302E-02
 0.500E 01    0.886E-01        0.465E-01        0.146E-01        0.524E-02        0.206E-02
 0.600E 01    0.825E-01        0.418E-01        0.123E-01        0.410E-02        0.151E-02
 0.700E 01    0.780E-01        0.385E-01        0.107E-01        0.336E-02        0.116E-02
 0.800E 01    0.746E-01        0.359E-01        0.946E-02        0.283E-02        0.934E-03
 0.900E 01    0.718E-01        0.339E-01        0.856E-02        0.245E-02        0.772E-03
 0.100E 02    0.695E-01        0.323E-01        0.785E-02        0.216E-02        0.654E-03
 0.150E 02    0.623E-01        0.273E-01        0.581E-02        0.139E-02        0.358E-03
 0.200E 02    0.584E-01        0.247E-01        0.483E-02        0.104E-02        0.245E-03
 0.250E 02    0.558E-01        0.231E-01        0.426E-02        0.861E-03        0.198E-03
 0.300E 02    0.539E-01        0.219E-01        0.389E-02        0.747E-03        0.154E-03
 0.400E 02    0.512E-01        0.204E-01        0.342E-02        0.612E-03        0.117E-03
 0.500E 02    0.493E-01        0.193E-01        0.312E-02        0.535E-03        0.964E-04
 0.600E 02    0.478E-01        0.186E-01        0.292E-02        0.484E-03        0.839E-04
 0.700E 02    0.465E-01        0.179E-01        0.277E-02        0.447E-03        0.753E-04
 0.800E 02    0.454E-01        0.174E-01        0.265E-02        0.420E-03        0.691E-04
 0.900E 02    0.444E-01        0.170E-01        0.255E-02        0.398E-03        0.642E-04
 0.100E 03    0.435E-01        0.166E-01        0.247E-02        0.380E-03        0.604E-04
 0.150E 03    0.399E-01        0.150E-01        0.217E-02        0.322E-03        0.497E-04
 0.200E 03    0.372E-01        0.139E-01        0.198E-02        0.287E-03        0.424E-04
 0.300E 03    0.332E-01        0.124E-01        0.173E-02        0.246E-03        0.353E-04
 0.400E 03    0.303E-01        0.112E-01        0.156E-02        0.219E-03        0.310E-04
 0.500E 03    0.281E-01        0.104E-01        0.144E-02        0.200E-03        0.281E-04
 0.600E 03    0.263E-01        0.972E-02        0.134E-02        0.186E-03        0.259E-04
 0.700E 03    0.248E-01        0.916E-02        0.126E-02        0.174E-03        0.242E-04
 0.800E 03    0.235E-01        0.869E-02        0.119E-02        0.164E-03        0.227E-04
 0.900E 03    0.224E-01        0.828E-02        0.113E-02        0.156E-03        0.216E-04
 0.100E 04    0.215E-01        0.793E-02        0.108E-02        0.149E-03        0.205E-04
------------------------------------------------------------------------------------------
```

```
TABLE 13:  XD VERSUS CD FOR SIGD =  0.200E 02

---------------------------------------------------------------------------------------------------
             LAMD= 0.000E 00  LAMD= 0.400E-01  LAMD= 0.100E 00  LAMD= 0.200E 00  LAMD= 0.300E 00
  XD-VALUE      CD-VALUE         CD-VALUE         CD-VALUE         CD-VALUE         CD-VALUE

---------------------------------------------------------------------------------------------------
 0.100E 01     0.999E 00        0.960E 00        0.908E 00        0.832E 00        0.767E 00
 0.150E 01     0.998E 00        0.960E 00        0.906E 00        0.827E 00        0.759E 00
 0.200E 01     0.998E 00        0.959E 00        0.905E 00        0.824E 00        0.754E 00
 0.300E 01     0.996E 00        0.958E 00        0.903E 00        0.821E 00        0.748E 00
 0.400E 01     0.995E 00        0.956E 00        0.902E 00        0.819E 00        0.745E 00
 0.500E 01     0.994E 00        0.955E 00        0.900E 00        0.817E 00        0.743E 00
 0.600E 01     0.993E 00        0.954E 00        0.899E 00        0.815E 00        0.741E 00
 0.700E 01     0.991E 00        0.953E 00        0.898E 00        0.814E 00        0.739E 00
 0.800E 01     0.990E 00        0.951E 00        0.897E 00        0.813E 00        0.738E 00
 0.900E 01     0.989E 00        0.950E 00        0.895E 00        0.812E 00        0.736E 00
 0.100E 02     0.988E 00        0.949E 00        0.894E 00        0.810E 00        0.735E 00
 0.150E 02     0.982E 00        0.943E 00        0.889E 00        0.805E 00        0.730E 00
 0.200E 02     0.976E 00        0.938E 00        0.883E 00        0.800E 00        0.725E 00
 0.250E 02     0.970E 00        0.932E 00        0.878E 00        0.795E 00        0.720E 00
 0.300E 02     0.965E 00        0.927E 00        0.873E 00        0.790E 00        0.716E 00
 0.400E 02     0.954E 00        0.916E 00        0.863E 00        0.781E 00        0.707E 00
 0.500E 02     0.943E 00        0.906E 00        0.853E 00        0.772E 00        0.699E 00
 0.600E 02     0.933E 00        0.896E 00        0.844E 00        0.764E 00        0.692E 00
 0.700E 02     0.923E 00        0.887E 00        0.835E 00        0.756E 00        0.684E 00
 0.800E 02     0.913E 00        0.877E 00        0.826E 00        0.748E 00        0.677E 00
 0.900E 02     0.904E 00        0.865E 00        0.818E 00        0.740E 00        0.670E 00
 0.100E 03     0.895E 00        0.860E 00        0.810E 00        0.733E 00        0.663E 00
 0.150E 03     0.853E 00        0.820E 00        0.772E 00        0.699E 00        0.632E 00
 0.200E 03     0.817E 00        0.785E 00        0.739E 00        0.669E 00        0.605E 00
 0.300E 03     0.756E 00        0.726E 00        0.694E 00        0.619E 00        0.560E 00
 0.400E 03     0.707E 00        0.680E 00        0.640E 00        0.579E 00        0.524E 00
 0.500E 03     0.667E 00        0.641E 00        0.603E 00        0.546E 00        0.494E 00
 0.600E 03     0.633E 00        0.608E 00        0.572E 00        0.518E 00        0.469E 00
 0.700E 03     0.603E 00        0.580E 00        0.546E 00        0.494E 00        0.447E 00
 0.800E 03     0.577E 00        0.555E 00        0.523E 00        0.473E 00        0.428E 00
 0.900E 03     0.555E 00        0.533E 00        0.502E 00        0.454E 00        0.411E 00
 0.100E 04     0.535E 00        0.514E 00        0.494E 00        0.438E 00        0.396E 00
---------------------------------------------------------------------------------------------------
```

TABLE 14: XD VERSUS CD FOR SIGD = 0.200E 02

XD-VALUE	LAMD= 0.400E 00 CD-VALUE	LAMD= 0.600E 00 CD-VALUE	LAMD= 0.800E 00 CD-VALUE	LAMD= 0.100E 01 CD-VALUE	LAMD= 0.120E 01 CD-VALUE
0.100E 01	0.710E 00	0.616E 00	0.542E 00	0.481E 00	0.430E 00
0.150E 01	0.698E 00	0.598E 00	0.518E 00	0.453E 00	0.399E 00
0.200E 01	0.692E 00	0.588E 00	0.504E 00	0.436E 00	0.380E 00
0.300E 01	0.684E 00	0.575E 00	0.488E 00	0.416E 00	0.358E 00
0.400E 01	0.680E 00	0.568E 00	0.479E 00	0.405E 00	0.345E 00
0.500E 01	0.676E 00	0.564E 00	0.472E 00	0.398E 00	0.337E 00
0.600E 01	0.674E 00	0.560E 00	0.468E 00	0.393E 00	0.331E 00
0.700E 01	0.672E 00	0.558E 00	0.465E 00	0.389E 00	0.327E 00
0.800E 01	0.670E 00	0.555E 00	0.462E 00	0.386E 00	0.323E 00
0.900E 01	0.669E 00	0.553E 00	0.460E 00	0.383E 00	0.320E 00
0.100E 02	0.668E 00	0.552E 00	0.458E 00	0.381E 00	0.318E 00
0.150E 02	0.662E 00	0.545E 00	0.451E 00	0.373E 00	0.310E 00
0.200E 02	0.657E 00	0.541E 00	0.446E 00	0.366E 00	0.305E 00
0.250E 02	0.653E 00	0.537E 00	0.442E 00	0.364E 00	0.301E 00
0.300E 02	0.649E 00	0.533E 00	0.438E 00	0.361E 00	0.298E 00
0.400E 02	0.641E 00	0.526E 00	0.432E 00	0.355E 00	0.293E 00
0.500E 02	0.633E 00	0.520E 00	0.427E 00	0.351E 00	0.288E 00
0.600E 02	0.626E 00	0.514E 00	0.422E 00	0.346E 00	0.285E 00
0.700E 02	0.619E 00	0.508E 00	0.417E 00	0.342E 00	0.281E 00
0.800E 02	0.613E 00	0.502E 00	0.412E 00	0.338E 00	0.278E 00
0.900E 02	0.607E 00	0.497E 00	0.408E 00	0.335E 00	0.275E 00
0.100E 03	0.600E 00	0.492E 00	0.404E 00	0.331E 00	0.272E 00
0.150E 03	0.572E 00	0.469E 00	0.384E 00	0.315E 00	0.258E 00
0.200E 03	0.548E 00	0.449E 00	0.368E 00	0.301E 00	0.247E 00
0.300E 03	0.507E 00	0.415E 00	0.340E 00	0.279E 00	0.228E 00
0.400E 03	0.474E 00	0.388E 00	0.318E 00	0.261E 00	0.214E 00
0.500E 03	0.447E 00	0.366E 00	0.300E 00	0.246E 00	0.201E 00
0.600E 03	0.424E 00	0.347E 00	0.285E 00	0.233E 00	0.191E 00
0.700E 03	0.404E 00	0.331E 00	0.271E 00	0.222E 00	0.182E 00
0.800E 03	0.387E 00	0.317E 00	0.260E 00	0.213E 00	0.174E 00
0.900E 03	0.372E 00	0.305E 00	0.249E 00	0.204E 00	0.167E 00
0.100E 04	0.358E 00	0.294E 00	0.240E 00	0.197E 00	0.161E 00

TABLE 15: XD VERSUS CD FOR SIGD = 0.200E 02

XD-VALUE	LAMD= 0.140E 01 CD-VALUE	LAMD= 0.160E 01 CD-VALUE	LAMD= 0.180E 01 CD-VALUE	LAMD= 0.200E 01 CD-VALUE	LAMD= 0.250E 01 CD-VALUE
0.100E 01	0.387E 00	0.350E 00	0.318E 00	0.290E 00	0.235E 00
0.150E 01	0.353E 00	0.315E 00	0.282E 00	0.253E 00	0.197E 00
0.200E 01	0.333E 00	0.293E 00	0.260E 00	0.231E 00	0.175E 00
0.300E 01	0.309E 00	0.268E 00	0.234E 00	0.205E 00	0.149E 00
0.400E 01	0.295E 00	0.254E 00	0.219E 00	0.190E 00	0.135E 00
0.500E 01	0.287E 00	0.245E 00	0.210E 00	0.180E 00	0.125E 00
0.600E 01	0.280E 00	0.238E 00	0.203E 00	0.173E 00	0.119E 00
0.700E 01	0.275E 00	0.233E 00	0.198E 00	0.168E 00	0.114E 00
0.800E 01	0.272E 00	0.229E 00	0.194E 00	0.164E 00	0.110E 00
0.900E 01	0.268E 00	0.226E 00	0.190E 00	0.161E 00	0.107E 00
0.100E 02	0.266E 00	0.223E 00	0.188E 00	0.158E 00	0.105E 00
0.150E 02	0.257E 00	0.215E 00	0.179E 00	0.150E 00	0.967E-01
0.200E 02	0.252E 00	0.209E 00	0.174E 00	0.145E 00	0.923E-01
0.250E 02	0.249E 00	0.206E 00	0.171E 00	0.142E 00	0.895E-01
0.300E 02	0.246E 00	0.203E 00	0.168E 00	0.139E 00	0.874E-01
0.400E 02	0.241E 00	0.199E 00	0.164E 00	0.136E 00	0.845E-01
0.500E 02	0.237E 00	0.195E 00	0.161E 00	0.133E 00	0.824E-01
0.600E 02	0.234E 00	0.193E 00	0.159E 00	0.131E 00	0.807E-01
0.700E 02	0.231E 00	0.190E 00	0.156E 00	0.129E 00	0.793E-01
0.800E 02	0.228E 00	0.188E 00	0.154E 00	0.127E 00	0.780E-01
0.900E 02	0.226E 00	0.185E 00	0.152E 00	0.125E 00	0.769E-01
0.100E 03	0.223E 00	0.183E 00	0.151E 00	0.124E 00	0.759E-01
0.150E 03	0.212E 00	0.174E 00	0.143E 00	0.117E 00	0.716E-01
0.200E 03	0.203E 00	0.166E 00	0.136E 00	0.112E 00	0.682E-01
0.300E 03	0.187E 00	0.153E 00	0.126E 00	0.103E 00	0.628E-01
0.400E 03	0.175E 00	0.143E 00	0.118E 00	0.963E-01	0.586E-01
0.500E 03	0.165E 00	0.135E 00	0.111E 00	0.907E-01	0.552E-01
0.600E 03	0.156E 00	0.128E 00	0.105E 00	0.860E-01	0.523E-01
0.700E 03	0.149E 00	0.122E 00	0.100E 00	0.819E-01	0.498E-01
0.800E 03	0.143E 00	0.117E 00	0.957E-01	0.784E-01	0.476E-01
0.900E 03	0.137E 00	0.112E 00	0.919E-01	0.753E-01	0.457E-01
0.100E 04	0.132E 00	0.108E 00	0.886E-01	0.725E-01	0.441E-01

TABLE 16: XD VERSUS CD FOR SIGD = 0.200E 02

	LAMD= 0.300E 01	LAMD= 0.400E 01	LAMD= 0.600E 01	LAMD= 0.800E 01	LAMD= 0.100E 02
XD-VALUE	CD-VALUE	CD-VALUE	CD-VALUE	CD-VALUE	CD-VALUE
0.100E 01	0.193E 00	0.135E 00	0.738E-01	0.440E-01	0.278E-01
0.150E 01	0.156E 00	0.103E 00	0.498E-01	0.267E-01	0.153E-01
0.200E 01	0.135E 00	0.843E-01	0.372E-01	0.183E-01	0.972E-02
0.300E 01	0.111E 00	0.642E-01	0.245E-01	0.106E-01	0.495E-02
0.400E 01	0.975E-01	0.533E-01	0.183E-01	0.711E-02	0.303E-02
0.500E 01	0.889E-01	0.466E-01	0.147E-01	0.525E-02	0.206E-02
0.600E 01	0.829E-01	0.420E-01	0.123E-01	0.412E-02	0.151E-02
0.700E 01	0.784E-01	0.387E-01	0.107E-01	0.337E-02	0.117E-02
0.800E 01	0.750E-01	0.361E-01	0.951E-02	0.285E-02	0.938E-03
0.900E 01	0.723E-01	0.341E-01	0.861E-02	0.246E-02	0.776E-03
0.100E 02	0.700E-01	0.325E-01	0.790E-02	0.217E-02	0.657E-03
0.150E 02	0.631E-01	0.276E-01	0.587E-02	0.139E-02	0.352E-03
0.200E 02	0.593E-01	0.251E-01	0.490E-02	0.106E-02	0.248E-03
0.250E 02	0.569E-01	0.235E-01	0.434E-02	0.877E-03	0.191E-03
0.300E 02	0.552E-01	0.225E-01	0.398E-02	0.763E-03	0.157E-03
0.400E 02	0.529E-01	0.210E-01	0.352E-02	0.630E-03	0.120E-03
0.500E 02	0.513E-01	0.201E-01	0.324E-02	0.555E-03	0.999E-04
0.600E 02	0.500E-01	0.194E-01	0.306E-02	0.505E-03	0.876E-04
0.700E 02	0.490E-0	0.189E-01	0.292E-02	0.470E-03	0.791E-04
0.800E 02	0.481E-01	0.185E-01	0.281E-02	0.444E-03	0.730E-04
0.900E 02	0.474E-01	0.181E-01	0.272E-02	0.423E-03	0.683E-04
0.100E 03	0.467E-01	0.178E-01	0.264E-02	0.407E-03	0.646E-04
0.150E 03	0.439E-01	0.165E-01	0.239E-02	0.353E-03	0.534E-04
0.200E 03	0.417E-01	0.156E-01	0.222E-02	0.322E-03	0.474E-04
0.300E 03	0.383E-01	0.143E-01	0.200E-02	0.283E-03	0.406E-04
0.400E 03	0.357E-01	0.132E-01	0.184E-02	0.258E-03	0.365E-04
0.500E 03	0.336E-01	0.124E-01	0.172E-02	0.239E-03	0.336E-04
0.600E 03	0.318E-01	0.118E-01	0.162E-02	0.225E-03	0.313E-04
0.700E 03	0.303E-01	0.112E-01	0.154E-02	0.212E-03	0.295E-04
0.800E 03	0.289E-01	0.107E-01	0.147E-02	0.202E-03	0.280E-04
0.900E 03	0.278E-01	0.103E-01	0.141E-02	0.193E-03	0.267E-04
0.100E 04	0.268E-01	0.988E-02	0.135E-02	0.186E-03	0.256E-04

TABLE 17: XD VERSUS CD FOR SIGD = 0.250E 02

XD-VALUE	LAMD= 0.000E 00 CD-VALUE	LAMD= 0.400E-01 CD-VALUE	LAMD= 0.100E 00 CD-VALUE	LAMD= 0.200E 00 CD-VALUE	LAMD= 0.300E 00 CD-VALUE
0.100E 01	0.999E 00	0.961E 00	0.908E 00	0.832E 00	0.767E 00
0.150E 01	0.999E 00	0.960E 00	0.907E 00	0.828E 00	0.759E 00
0.200E 01	0.998E 00	0.960E 00	0.906E 00	0.825E 00	0.754E 00
0.300E 01	0.998E 00	0.959E 00	0.904E 00	0.822E 00	0.749E 00
0.400E 01	0.997E 00	0.958E 00	0.903E 00	0.820E 00	0.746E 00
0.500E 01	0.996E 00	0.957E 00	0.902E 00	0.819E 00	0.744E 00
0.600E 01	0.995E 00	0.956E 00	0.901E 00	0.818E 00	0.743E 00
0.700E 01	0.994E 00	0.956E 00	0.901E 00	0.817E 00	0.741E 00
0.800E 01	0.994E 00	0.955E 00	0.900E 00	0.816E 00	0.740E 00
0.900E 01	0.993E 00	0.954E 00	0.899E 00	0.815E 00	0.739E 00
0.100E 02	0.992E 00	0.953E 00	0.898E 00	0.814E 00	0.738E 00
0.150E 02	0.988E 00	0.950E 00	0.895E 00	0.810E 00	0.734E 00
0.200E 02	0.984E 00	0.946E 00	0.891E 00	0.807E 00	0.731E 00
0.250E 02	0.981E 00	0.942E 00	0.888E 00	0.804E 00	0.728E 00
0.300E 02	0.977E 00	0.939E 00	0.884E 00	0.800E 00	0.725E 00
0.400E 02	0.969E 00	0.932E 00	0.877E 00	0.794E 00	0.719E 00
0.500E 02	0.962E 00	0.925E 00	0.871E 00	0.788E 00	0.714E 00
0.600E 02	0.955E 00	0.918E 00	0.864E 00	0.782E 00	0.708E 00
0.700E 02	0.948E 00	0.911E 00	0.858E 00	0.777E 00	0.703E 00
0.800E 02	0.942E 00	0.905E 00	0.852E 00	0.771E 00	0.698E 00
0.900E 02	0.935E 00	0.898E 00	0.846E 00	0.766E 00	0.693E 00
0.100E 03	0.929E 00	0.892E 00	0.840E 00	0.760E 00	0.688E 00
0.150E 03	0.898E 00	0.863E 00	0.813E 00	0.736E 00	0.666E 00
0.200E 03	0.870E 00	0.836E 00	0.788E 00	0.713E 00	0.645E 00
0.300E 03	0.822E 00	0.790E 00	0.744E 00	0.673E 00	0.609E 00
0.400E 03	0.781E 00	0.750E 00	0.707E 00	0.640E 00	0.579E 00
0.500E 03	0.745E 00	0.716E 00	0.675E 00	0.610E 00	0.552E 00
0.600E 03	0.714E 00	0.686E 00	0.646E 00	0.585E 00	0.529E 00
0.700E 03	0.687E 00	0.660E 00	0.622E 00	0.562E 00	0.509E 00
0.800E 03	0.662E 00	0.636E 00	0.599E 00	0.542E 00	0.491E 00
0.900E 03	0.640E 00	0.615E 00	0.579E 00	0.524E 00	0.474E 00
0.100E 04	0.620E 00	0.596E 00	0.561E 00	0.508E 00	0.460E 00

TABLE 15: XD VERSUS CD FOR SIGD = 0.250E 02

XD-VALUE	LAMD= 0.400E 00 CD-VALUE	LAMD= 0.600E 00 CD-VALUE	LAMD= 0.800E 00 CD-VALUE	LAMD= 0.100E 01 CD-VALUE	LAMD= 0.120E 01 CD-VALUE
0.100E 01	0.710E 00	0.616E 00	0.542E 00	0.481E 00	0.430E 00
0.150E 01	0.699E 00	0.598E 00	0.518E 00	0.453E 00	0.399E 00
0.200E 01	0.692E 00	0.588E 00	0.504E 00	0.436E 00	0.380E 00
0.300E 01	0.685E 00	0.576E 00	0.488E 00	0.417E 00	0.358E 00
0.400E 01	0.681E 00	0.569E 00	0.479E 00	0.406E 00	0.346E 00
0.500E 01	0.678E 00	0.565E 00	0.473E 00	0.399E 00	0.338E 00
0.600E 01	0.676E 00	0.562E 00	0.469E 00	0.394E 00	0.332E 00
0.700E 01	0.674E 00	0.559E 00	0.466E 00	0.390E 00	0.327E 00
0.800E 01	0.673E 00	0.557E 00	0.463E 00	0.387E 00	0.324E 00
0.900E 01	0.671E 00	0.555E 00	0.461E 00	0.384E 00	0.321E 00
0.100E 02	0.670E 00	0.554E 00	0.459E 00	0.382E 00	0.319E 00
0.150E 02	0.666E 00	0.549E 00	0.453E 00	0.375E 00	0.311E 00
0.200E 02	0.663E 00	0.545E 00	0.449E 00	0.371E 00	0.307E 00
0.250E 02	0.660E 00	0.542E 00	0.446E 00	0.368E 00	0.304E 00
0.300E 02	0.657E 00	0.540E 00	0.444E 00	0.365E 00	0.301E 00
0.400E 02	0.651E 00	0.535E 00	0.439E 00	0.361E 00	0.297E 00
0.500E 02	0.646E 00	0.530E 00	0.435E 00	0.358E 00	0.294E 00
0.600E 02	0.641E 00	0.526E 00	0.432E 00	0.355E 00	0.291E 00
0.700E 02	0.637E 00	0.522E 00	0.428E 00	0.352E 00	0.289E 00
0.800E 02	0.632E 00	0.518E 00	0.425E 00	0.349E 00	0.286E 00
0.900E 02	0.627E 00	0.514E 00	0.422E 00	0.346E 00	0.284E 00
0.100E 03	0.623E 00	0.511E 00	0.419E 00	0.344E 00	0.282E 00
0.150E 03	0.602E 00	0.494E 00	0.405E 00	0.332E 00	0.272E 00
0.200E 03	0.584E 00	0.478E 00	0.392E 00	0.321E 00	0.263E 00
0.300E 03	0.551E 00	0.452E 00	0.370E 00	0.303E 00	0.248E 00
0.400E 03	0.524E 00	0.429E 00	0.351E 00	0.288E 00	0.236E 00
0.500E 03	0.500E 00	0.409E 00	0.335E 00	0.275E 00	0.225E 00
0.600E 03	0.479E 00	0.392E 00	0.321E 00	0.263E 00	0.216E 00
0.700E 03	0.461E 00	0.377E 00	0.309E 00	0.253E 00	0.207E 00
0.800E 03	0.444E 00	0.364E 00	0.298E 00	0.244E 00	0.200E 00
0.900E 03	0.429E 00	0.352E 00	0.258E 00	0.236E 00	0.193E 00
0.100E 04	0.416E 00	0.341E 00	0.279E 00	0.228E 00	0.187E 00

TABLE 19: XD VERSUS CD FOR SIGD = 0.250E 02

XD-VALUE	LAMD= 0.140E 01 CD-VALUE	LAMD= 0.160E 01 CD-VALUE	LAMD= 0.180E 01 CD-VALUE	LAMD= 0.200E 01 CD-VALUE	LAMD= 0.250E 01 CD-VALUE
0.100E 01	0.397E 00	0.350E 00	0.318E 00	0.290E 00	0.235E 00
0.150E 01	0.353E 00	0.315E 00	0.282E 00	0.253E 00	0.197E 00
0.200E 01	0.333E 00	0.293E 00	0.260E 00	0.231E 00	0.175E 00
0.300E 01	0.309E 00	0.269E 00	0.234E 00	0.205E 00	0.150E 00
0.400E 01	0.296E 00	0.254E 00	0.220E 00	0.190E 00	0.135E 00
0.500E 01	0.287E 00	0.245E 00	0.210E 00	0.181E 00	0.126E 00
0.600E 01	0.281E 00	0.238E 00	0.203E 00	0.174E 00	0.119E 00
0.700E 01	0.276E 00	0.234E 00	0.198E 00	0.169E 00	0.114E 00
0.800E 01	0.272E 00	0.230E 00	0.194E 00	0.165E 00	0.110E 00
0.900E 01	0.269E 00	0.227E 00	0.191E 00	0.162E 00	0.107E 00
0.100E 02	0.267E 00	0.224E 00	0.188E 00	0.159E 00	0.105E 00
0.150E 02	0.259E 00	0.216E 00	0.180E 00	0.151E 00	0.972E-01
0.200E 02	0.254E 00	0.211E 00	0.176E 00	0.146E 00	0.930E-01
0.250E 02	0.251E 00	0.208E 00	0.172E 00	0.143E 00	0.904E-01
0.300E 02	0.249E 00	0.206E 00	0.170E 00	0.141E 00	0.884E-01
0.400E 02	0.245E 00	0.202E 00	0.167E 00	0.138E 00	0.858E-01
0.500E 02	0.242E 00	0.199E 00	0.164E 00	0.136E 00	0.840E-01
0.600E 02	0.240E 00	0.197E 00	0.162E 00	0.134E 00	0.826E-01
0.700E 02	0.237E 00	0.195E 00	0.161E 00	0.132E 00	0.814E-01
0.800E 02	0.235E 00	0.193E 00	0.159E 00	0.131E 00	0.804E-01
0.900E 02	0.233E 00	0.192E 00	0.157E 00	0.129E 00	0.795E-01
0.100E 03	0.231E 00	0.190E 00	0.156E 00	0.128E 00	0.787E-01
0.150E 03	0.223E 00	0.183E 00	0.150E 00	0.123E 00	0.754E-01
0.200E 03	0.216E 00	0.177E 00	0.145E 00	0.119E 00	0.727E-01
0.300E 03	0.204E 00	0.167E 00	0.137E 00	0.112E 00	0.683E-01
0.400E 03	0.193E 00	0.158E 00	0.130E 00	0.106E 00	0.647E-01
0.500E 03	0.184E 00	0.151E 00	0.124E 00	0.101E 00	0.616E-01
0.600E 03	0.177E 00	0.145E 00	0.118E 00	0.971E-01	0.590E-01
0.700E 03	0.170E 00	0.139E 00	0.114E 00	0.933E-01	0.567E-01
0.800E 03	0.164E 00	0.134E 00	0.110E 00	0.899E-01	0.546E-01
0.900E 03	0.158E 00	0.130E 00	0.106E 00	0.869E-01	0.528E-01
0.100E 04	0.153E 00	0.125E 00	0.103E 00	0.842E-01	0.511E-01

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TABLE 20: XD VERSUS CD FOR SIGD = 0.250E 02

XD-VALUE	LAMD= 0.300E 01 CD-VALUE	LAMD= 0.400E 01 CD-VALUE	LAMD= 0.600E 01 CD-VALUE	LAMD= 0.800E 01 CD-VALUE	LAMD= 0.100E 02 CD-VALUE
0.100E 01	0.193E 00	0.135E 00	0.738E-01	0.440E-01	0.278E-01
0.150E 01	0.157E 00	0.103E 00	0.498E-01	0.267E-01	0.153E-01
0.200E 01	0.135E 00	0.843E-01	0.372E-01	0.153E-01	0.972E-02
0.300E 01	0.111E 00	0.642E-01	0.245E-01	0.106E-01	0.495E-02
0.400E 01	0.976E-01	0.534E-01	0.153E-01	0.711E-02	0.303E-02
0.500E 01	0.890E-01	0.467E-01	0.147E-01	0.525E-02	0.207E-02
0.600E 01	0.830E-01	0.421E-01	0.123E-01	0.412E-02	0.152E-02
0.700E 01	0.786E-01	0.387E-01	0.107E-01	0.337E-02	0.117E-02
0.800E 01	0.752E-01	0.362E-01	0.953E-02	0.285E-02	0.940E-03
0.900E 01	0.725E-01	0.342E-01	0.863E-02	0.247E-02	0.777E-03
0.100E 02	0.703E-01	0.326E-01	0.792E-02	0.218E-02	0.659E-03
0.150E 02	0.634E-01	0.278E-01	0.590E-02	0.140E-02	0.363E-03
0.200E 02	0.598E-01	0.253E-01	0.494E-02	0.107E-02	0.250E-03
0.250E 02	0.575E-01	0.238E-01	0.438E-02	0.884E-03	0.192E-03
0.300E 02	0.559E-01	0.227E-01	0.402E-02	0.771E-03	0.159E-03
0.400E 02	0.537E-01	0.214E-01	0.357E-02	0.639E-03	0.122E-03
0.500E 02	0.523E-01	0.205E-01	0.331E-02	0.565E-03	0.102E-03
0.600E 02	0.512E-01	0.199E-01	0.312E-02	0.516E-03	0.894E-04
0.700E 02	0.503E-01	0.194E-01	0.299E-02	0.482E-03	0.811E-04
0.800E 02	0.496E-01	0.190E-01	0.289E-02	0.457E-03	0.751E-04
0.900E 02	0.490E-01	0.187E-01	0.281E-02	0.437E-03	0.705E-04
0.100E 03	0.484E-01	0.184E-01	0.274E-02	0.421E-03	0.669E-04
0.150E 03	0.461E-01	0.174E-01	0.251E-02	0.371E-03	0.561E-04
0.200E 03	0.444E-01	0.166E-01	0.236E-02	0.342E-03	0.504E-04
0.300E 03	0.416E-01	0.155E-01	0.217E-02	0.307E-03	0.441E-04
0.400E 03	0.394E-01	0.146E-01	0.203E-02	0.284E-03	0.402E-04
0.500E 03	0.375E-01	0.139E-01	0.192E-02	0.267E-03	0.375E-04
0.600E 03	0.359E-01	0.133E-01	0.183E-02	0.253E-03	0.353E-04
0.700E 03	0.345E-01	0.127E-01	0.175E-02	0.242E-03	0.336E-04
0.800E 03	0.332E-01	0.123E-01	0.168E-02	0.232E-03	0.321E-04
0.900E 03	0.321E-01	0.118E-01	0.162E-02	0.223E-03	0.308E-04
0.100E 04	0.310E-01	0.115E-01	0.157E-02	0.215E-03	0.297E-04

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TABLE 21:  XD VERSUS CD FOR SIGD =  0.300E 02

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               LAMD= 0.000E 00  LAMD= 0.400E-01  LAMD= 0.100E 00  LAMD= 0.200E 00  LAMD= 0.300E 00
 XD-VALUE          CD-VALUE         CD-VALUE         CD-VALUE         CD-VALUE         CD-VALUE

---------------------------------------------------------------------------------------------------
0.100E 01         0.999E 00        0.961E 00        0.909E 00        0.832E 00        0.767E 00
0.150E 01         0.999E 00        0.961E 00        0.907E 00        0.828E 00        0.759E 00
0.200E 01         0.999E 00        0.960E 00        0.906E 00        0.825E 00        0.755E 00
0.300E 01         0.998E 00        0.959E 00        0.905E 00        0.823E 00        0.750E 00
0.400E 01         0.998E 00        0.959E 00        0.904E 00        0.821E 00        0.747E 00
0.500E 01         0.997E 00        0.958E 00        0.903E 00        0.820E 00        0.745E 00
0.600E 01         0.997E 00        0.958E 00        0.903E 00        0.819E 00        0.744E 00
0.700E 01         0.996E 00        0.957E 00        0.902E 00        0.818E 00        0.743E 00
0.800E 01         0.996E 00        0.957E 00        0.901E 00        0.817E 00        0.742E 00
0.900E 01         0.995E 00        0.956E 00        0.901E 00        0.817E 00        0.741E 00
0.100E 02         0.994E 00        0.956E 00        0.900E 00        0.816E 00        0.740E 00
0.150E 02         0.992E 00        0.953E 00        0.898E 00        0.813E 00        0.737E 00
0.200E 02         0.989E 00        0.950E 00        0.895E 00        0.811E 00        0.734E 00
0.250E 02         0.986E 00        0.948E 00        0.893E 00        0.808E 00        0.732E 00
0.300E 02         0.984E 00        0.945E 00        0.890E 00        0.806E 00        0.730E 00
0.400E 02         0.979E 00        0.940E 00        0.886E 00        0.802E 00        0.726E 00
0.500E 02         0.973E 00        0.935E 00        0.881E 00        0.797E 00        0.722E 00
0.600E 02         0.968E 00        0.930E 00        0.876E 00        0.793E 00        0.718E 00
0.700E 02         0.963E 00        0.926E 00        0.872E 00        0.789E 00        0.714E 00
0.800E 02         0.958E 00        0.921E 00        0.867E 00        0.785E 00        0.710E 00
0.900E 02         0.953E 00        0.916E 00        0.863E 00        0.781E 00        0.707E 00
0.100E 03         0.949E 00        0.912E 00        0.859E 00        0.777E 00        0.703E 00
0.150E 03         0.926E 00        0.890E 00        0.838E 00        0.758E 00        0.686E 00
0.200E 03         0.905E 00        0.869E 00        0.819E 00        0.741E 00        0.670E 00
0.300E 03         0.865E 00        0.832E 00        0.794E 00        0.709E 00        0.642E 00
0.400E 03         0.832E 00        0.800E 00        0.753E 00        0.681E 00        0.617E 00
0.500E 03         0.802E 00        0.770E 00        0.726E 00        0.657E 00        0.594E 00
0.600E 03         0.775E 00        0.744E 00        0.701E 00        0.634E 00        0.574E 00
0.700E 03         0.750E 00        0.721E 00        0.679E 00        0.614E 00        0.556E 00
0.800E 03         0.728E 00        0.699E 00        0.658E 00        0.596E 00        0.539E 00
0.900E 03         0.707E 00        0.679E 00        0.640E 00        0.579E 00        0.524E 00
0.100E 04         0.688E 00        0.661E 00        0.623E 00        0.564E 00        0.510E 00
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TABLE 22: XD VERSUS CD FOR SIGD = 0.300E 02

XD-VALUE	LAMD= 0.400E 00 CD-VALUE	LAMD= 0.600E 00 CD-VALUE	LAMD= 0.800E 00 CD-VALUE	LAMD= 0.100E 01 CD-VALUE	LAMD= 0.120E 01 CD-VALUE
0.100E 01	0.710E 00	0.617E 00	0.542E 00	0.481E 00	0.430E 00
0.150E 01	0.699E 00	0.599E 00	0.518E 00	0.453E 00	0.399E 00
0.200E 01	0.693E 00	0.588E 00	0.505E 00	0.436E 00	0.380E 00
0.300E 01	0.685E 00	0.576E 00	0.489E 00	0.417E 00	0.358E 00
0.400E 01	0.681E 00	0.570E 00	0.480E 00	0.406E 00	0.346E 00
0.500E 01	0.679E 00	0.565E 00	0.474E 00	0.399E 00	0.338E 00
0.600E 01	0.677E 00	0.562E 00	0.470E 00	0.394E 00	0.332E 00
0.700E 01	0.675E 00	0.560E 00	0.467E 00	0.390E 00	0.328E 00
0.800E 01	0.674E 00	0.558E 00	0.464E 00	0.387E 00	0.325E 00
0.900E 01	0.673E 00	0.557E 00	0.462E 00	0.385E 00	0.322E 00
0.100E 02	0.672E 00	0.555E 00	0.460E 00	0.383E 00	0.320E 00
0.150E 02	0.668E 00	0.551E 00	0.455E 00	0.377E 00	0.312E 00
0.200E 02	0.666E 00	0.548E 00	0.451E 00	0.373E 00	0.308E 00
0.250E 02	0.663E 00	0.545E 00	0.449E 00	0.370E 00	0.306E 00
0.300E 02	0.661E 00	0.543E 00	0.447E 00	0.368E 00	0.303E 00
0.400E 02	0.657E 00	0.540E 00	0.443E 00	0.365E 00	0.300E 00
0.500E 02	0.654E 00	0.536E 00	0.440E 00	0.362E 00	0.298E 00
0.600E 02	0.650E 00	0.533E 00	0.438E 00	0.359E 00	0.295E 00
0.700E 02	0.647E 00	0.530E 00	0.435E 00	0.357E 00	0.293E 00
0.800E 02	0.643E 00	0.527E 00	0.432E 00	0.355E 00	0.291E 00
0.900E 02	0.640E 00	0.524E 00	0.430E 00	0.353E 00	0.290E 00
0.100E 03	0.637E 00	0.522E 00	0.428E 00	0.351E 00	0.288E 00
0.150E 03	0.621E 00	0.509E 00	0.417E 00	0.342E 00	0.280E 00
0.200E 03	0.607E 00	0.497E 00	0.407E 00	0.334E 00	0.274E 00
0.300E 03	0.581E 00	0.476E 00	0.390E 00	0.319E 00	0.262E 00
0.400E 03	0.558E 00	0.457E 00	0.374E 00	0.307E 00	0.251E 00
0.500E 03	0.538E 00	0.440E 00	0.361E 00	0.295E 00	0.242E 00
0.600E 03	0.519E 00	0.425E 00	0.348E 00	0.285E 00	0.234E 00
0.700E 03	0.503E 00	0.412E 00	0.337E 00	0.276E 00	0.226E 00
0.800E 03	0.488E 00	0.400E 00	0.327E 00	0.268E 00	0.219E 00
0.900E 03	0.474E 00	0.388E 00	0.318E 00	0.260E 00	0.213E 00
0.100E 04	0.461E 00	0.378E 00	0.309E 00	0.253E 00	0.208E 00

```
TABLE 23:  XD VERSUS CD FOR SIGD =  0.300E 02

------------------------------------------------------------------------------------------------
             LAMD= 0.140E 01  LAMD= 0.160E 01  LAMD= 0.180E 01  LAMD= 0.200E 01  LAMD= 0.250E 01
  XD-VALUE      CD-VALUE         CD-VALUE         CD-VALUE         CD-VALUE         CD-VALUE

------------------------------------------------------------------------------------------------
0.100E 01      0.387E 00        0.350E 00        0.318E 00        0.290E 00        0.235E 00
0.150E 01      0.353E 00        0.315E 00        0.282E 00        0.253E 00        0.197E 00
0.200E 01      0.333E 00        0.294E 00        0.260E 00        0.231E 00        0.175E 00
0.300E 01      0.310E 00        0.269E 00        0.234E 00        0.205E 00        0.150E 00
0.400E 01      0.296E 00        0.255E 00        0.220E 00        0.190E 00        0.135E 00
0.500E 01      0.287E 00        0.245E 00        0.210E 00        0.181E 00        0.126E 00
0.600E 01      0.281E 00        0.239E 00        0.203E 00        0.174E 00        0.119E 00
0.700E 01      0.276E 00        0.234E 00        0.198E 00        0.169E 00        0.114E 00
0.800E 01      0.273E 00        0.230E 00        0.195E 00        0.165E 00        0.111E 00
0.900E 01      0.270E 00        0.227E 00        0.191E 00        0.162E 00        0.108E 00
0.100E 02      0.266E 00        0.224E 00        0.189E 00        0.159E 00        0.105E 00
0.150E 02      0.260E 00        0.216E 00        0.181E 00        0.151E 00        0.975E-01
0.200E 02      0.256E 00        0.212E 00        0.176E 00        0.147E 00        0.934E-01
0.250E 02      0.253E 00        0.209E 00        0.173E 00        0.144E 00        0.908E-01
0.300E 02      0.250E 00        0.207E 00        0.171E 00        0.142E 00        0.890E-01
0.400E 02      0.247E 00        0.204E 00        0.168E 00        0.139E 00        0.866E-01
0.500E 02      0.245E 00        0.202E 00        0.166E 00        0.137E 00        0.849E-01
0.600E 02      0.243E 00        0.200E 00        0.164E 00        0.135E 00        0.837E-01
0.700E 02      0.241E 00        0.198E 00        0.163E 00        0.134E 00        0.827E-01
0.800E 02      0.239E 00        0.197E 00        0.162E 00        0.133E 00        0.818E-01
0.900E 02      0.238E 00        0.195E 00        0.161E 00        0.132E 00        0.811E-01
0.100E 03      0.236E 00        0.194E 00        0.159E 00        0.131E 00        0.804E-01
0.150E 03      0.230E 00        0.189E 00        0.155E 00        0.127E 00        0.777E-01
0.200E 03      0.224E 00        0.184E 00        0.151E 00        0.124E 00        0.755E-01
0.300E 03      0.214E 00        0.176E 00        0.144E 00        0.118E 00        0.719E-01
0.400E 03      0.206E 00        0.169E 00        0.138E 00        0.113E 00        0.689E-01
0.500E 03      0.198E 00        0.162E 00        0.133E 00        0.109E 00        0.663E-01
0.600E 03      0.191E 00        0.157E 00        0.128E 00        0.105E 00        0.640E-01
0.700E 03      0.125E 00        0.152E 00        0.124E 00        0.102E 00        0.619E-01
0.800E 03      0.180E 00        0.147E 00        0.121E 00        0.988E-01        0.600E-01
0.900E 03      0.175E 00        0.143E 00        0.117E 00        0.960E-01        0.583E-01
0.100E 04      0.170E 00        0.139E 00        0.114E 00        0.934E-01        0.567E-01
------------------------------------------------------------------------------------------------
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APPENDIX C #102

#102

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APP. C
(102)

Development of Land Disposal Banning Decisions Under Uncertainty

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APPENDIX C

Development of Land Disposal Banning Decisions Under Uncertainty

1.0 Introduction

1.1 Background and Relevant History

Increasingly, the Agency is required to regulate the use or disposal of toxic chemicals including hazardous wastes before such materials become part of a specific, permitted system for use or disposal. The regulatory approach developed in response to such legislative mandates is necessarily generic in nature and must be largely based upon inherent chemical properties. In general, however, the behavior of specific chemicals in the environment and the subsequent health risks posed to populations are highly dependent on both the environmental setting and the chemical properties.

An obvious dilemma arises from the requirement to regulate (based on risks posed to human health) on a national basis when the exposure is determined by a combination of site- and chemical-specific factors. The errors and uncertainties inherent in site-specific analyses are further complicated by uncertainty about how to properly specify a national environment. The land disposal restrictions requirements of the RCRA amendments pose just such a dilemma. Specifically, how can the Agency determine the national acceptability (or specify required treatment levels) of the land disposal of hazardous wastes based on an evaluation of risk to human health?

As initially conceived by the OSW, "screening levels were to be developed to specify maximum acceptable contaminant concentrations in waste extracts. Concentration-based fate and transport models for groundwater, air, and surface waters were to be developed for a "worst case" or "reasonable worst case" land disposal scenario to allow back calculation of acceptable leachate contaminations commencing from a reference dose (or a ql* concentration for carcinogens) at a point of potential human exposure at a specified distance directly down gradient (e.g. water supply well, surface water intake, or downwind exposure point). As this approach was further developed two major issues emerged: (1) how can the reasonable worst case be defined to avoid unrealistic situations and permit some site-specificity and; (2) how can the considerable uncertainties inherent in any analysis of this nature be factored into the process.

1.2 Objectives

The objectives of the material presented in the following sections are to develop and demonstrate a procedure for applying the initially-developed concept that accommodates the possible variation in environmental settings, the uncertainties in specific chemical properties, and the range of impact of engineered system releases from disposal facilities. The developed approach is intended to present decision-makers, for each chemical, the level of treatment (or restriction) required to achieve any desired level of "protection" expressed as the percentage of all possible land disposal scenarios that are more protective than the level chosen. In this manner the scenario selected can be evaluated for its probability of occurence. At one level one may say, for example, that 90% of all possible sites are more protective than the health based threshold while 10% of all possible sites are less protective. In this case the decision-maker can be assured that the level of treatment selected will ensure that downgradient concentrations will not exceed the specified target concentration in more than 10% of all possible environmental settings.

Meeting this overall objective requires that the following subobjectives be met:

- Identify and characterize the environmental and chemical properties contributing to variation in the release, fate, and transport of chemicals.
- Identify and characterize the errors in estimating or measuring relevant chemical properties.
- Develop a technique to synthesize input data for use in investigating model variations and uncertainties.

2.0 The Concept of Uncertainty

2.1 Definitions

Uncertainty is generally defined as the absence of information about the subject under consideration. In this context the absence or lack of information usually refers to information about past, present, or future events, values, or conditions. Rowe (1977) describes two basic types of uncertainty: (1) descriptive uncertainty and (2) measurement uncertainty. Descriptive uncertainty is a measure of the lack of information about the identity of variables that define the system under study. Measurement uncertainty is a measure of the lack of information about how to quantify those variables. Uncertainty analyses are typically completed for measurement uncertainty with the assistance of a system model that transforms inputs to outputs via some mathematical description of the "real world" system of interest. The objective is to quantify the model output uncertainties given a knowledge of the input uncertainties. Several formal methods exist to conduct such analyses as summarized by Cox and Baybutt (1981). Usually, such analyses do not address descriptive uncertainty. That is, the model itself is assumed to adequately describe the "real world" system being simulated. Uncertainty (descriptive) about the system model will almost always exist and in some cases this uncertainty is acknowledged but ignored because of policy objectives. In other cases, descriptive uncertainty is unknown (and unknowable) and is simply ignored.

2.2 Application to the Land Disposal Banning Process

The application of uncertainty analyses to the procedures developed for setting limits on land disposal is highly desirable. Indeed, the RCRA amendments directed that such regulations be developed with proper accounting for the long-term uncertainties of land disposal technologies. It follows that any provisions granted for continued use of land disposal should properly account for the uncertainties in the technical basis for such provisions. Following the previous discussion of uncertainty, two problems must be addressed: descriptive uncertainty and measurement uncertainty.

The choice of the models used in the procedure and the conceptualization of the physical system acknowledges the descriptive uncertainty in the process. In this sense, assumptions made about land disposal performance, location of fixed, downgradient exposure points, and the use of unit risk numbers (e.g., Reference Dose Values) are ways to include descriptive uncertainty. For example, it is generally conceded that landfills have and could in the future be designed such that their lower boundary is near or actually in the saturated zone. The uncertainty about this descriptive variable is simply handled by assuming all facilities are located such that any leakage will be directly to the saturated zone. Additional, specific assumptions and decisions imbedded in the procedure that fall into the descriptive uncertainty category are:

(1) all engineered systems fail given sufficient time

(2) the advective-dispersion equation with reaction and sorption is an accurate description of chemical fate and transport in groundwater, surface water, and air

(3) all processes that can degrade organics in groundwater other than hydrolysis are ignored

(4) for metals and organics, equilibrium, reversible speciation and sorption are appropriate

(5) the leach test (EP III) is an accurate measure of the leachate concentration resulting when failure of the facility occurs

(6) the contaminant source is sufficiently large in mass to enable an assumption of an infinite source, i.e., down gradient contamination once reached will be maintained

(7) transient behavior is unimportant and the overall response can be represented by steady-state estimates

Most of the assumptions listed above eliminate consideration of possible effects or variables that can conceivably lead to differences between the real and modeled systems. These expected differences resulting from omission of such effects represent uncertainty that is quantified only in one sense—their exclusion will result in a more conservative analysis. Conservative in this case simply means that a more restrictive outcome for land disposal is generated. To the extent that this is desired, the assumptions per se represent an accommodation of descriptive uncertainty. The modeling approach and its assumptions with their descriptive uncertainty in land-related hazardous waste management are consistent with the strong legislative presumption against land disposal.

The problem remains to evaluate measurement uncertainty. In this case, measurement is taken to mean assignment of specific values to each of the model variables and parameters. Once a model is chosen to represent the conceptualized system, specific values must be chosen to further describe the behavior of the modeled system. The groundwater model relies on two general types of data:

- data on the physical, chemical, and toxicological properties of the hazardous constituents (e.g., K_{OC}, K_{OW}, acid, neutral, and base-catalyzed hydrolysis rates, and Reference Dose)
- data on the environmental properties of land disposal settings that impact the release, fate, and transport of each hazardous constituent (e.g., groundwater velocity, thickness of the saturated zone, bulk density, groundwater temperature and pH, dispersivities)

Measurement uncertainty applied to the first data type is taken to mean the errors resulting from laboratory or theoretical analyses used to estimate their numerical values. In addition to experimental precision and accuracy, errors may arise in extrapolation from measurement conditions to environmental conditions (e.g., hydrolysis experiments conducted at elevated temperatures extrapolated to groundwater temperatures). For some parameters, most notably partition coefficients, semi-empirical methods are used to estimate values and in such cases the errors in the empiricisms contribute to uncertainty.

Measurement uncertainty applied to the second data type, characterization of the relevant environmental properties, is taken to mean the variation expected to occur across possible land disposal settings. In the strictest sense analyses of known variation are more properly referred to as sensitivity analyses. Within the context of defining the range of possible regulatory outcomes, however, we elect to describe the characterization of variation as representing uncertainty. An important distinction is made here between variation (and measurement errors in characterizing that variation) at a given site and variation from site to site. Variation within a site is an important phenomenon in site-specific issues like permit evaluations, designs, and remedial action alternatives. The uncertainty in the performance of a given system will in large part reflect the uncertainty about the characterization of the given site. For example, the location of down-gradient monitoring wells to detect future leaks is chosen based on measurements that define the direction of groundwater flow. If uncertainty exists in the determination of the flow direction, then the performance of the detection system is also made uncertain. This "within-site" variation is not the most important source of uncertainty, however, for the land disposal banning process because we are concerned with a presumed national (generic) site. The major concern for this case is uncertainty in specifying the range of possible sites.

The generic nature of the present regulatory process leads to a major uncertainty in characterization of the presumed national site. Assuming it is possible to accurately measure site properties (e.g., groundwater velocities and pH) the problem reduces to one of properly specifying the many possible combinations of conditions that can exist in possible sites for land disposal. Uncertainty in this sense, is simply an explicit representation of the variation in site conditions that can exist. From such information the levels chosen for regulating land disposal restrictions can be easily referenced to the full range of possible outcomes or restrictions.

3.0 Technical Approach

3.1 Monte Carlo Analyses

The recent review by Cox and Baybutt (1981) noted five different methods for conducting uncertainty analyses. The choice of any one method is largely determined by the structure of the system model and the objective of the analyses. In some cases the methods are quite limited because of the requirements imposed for their use. For example, analytic techniques require a mathematically tractable system model that permits direct calculation of output uncertainties given the input distributions. In some cases, knowledge about the source of the output uncertainty given a multitude of possible input uncertainties is needed in order to minimize or reduce uncertainty; for these cases, techniques that randomly combine individual inputs to produce a single output are unacceptable because it is not possible to know the source of the uncertainty. However, the monte carlo method remains the most widely-used procedure and is suitable for investigating the land disposal restrictions process.

Before further elaboration on the monte carlo method it is useful to review the needs for the land disposal restrictions process:

(1) portray in a concise manner the field of information describing an estimate of all possible exposures

(2) demonstrate that all reasonable steps were taken to reflect the wide range of possible site conditions for land disposal systems

(3) investigate the range and distribution of possible restrictions needed to insure specified levels of protection

(4) properly reflect the uncertainty introduced by laboratory-measured model parameters for hydrolysis and sorption

The emphasis here is on the output of the modeling process. The exact cause of output variation is less important at this stage of developing the restrictions. For these reasons, the monte carlo approach is appropriate, relatively easy to implement, and computationly efficient for the system model used.

Figure 1 illustrates the monte carlo procedure used in this analysis. If G(X) represents the desired output distribution for a given variable, i.e., C_L, the acceptable leachate concentration, then the process is represented by:

$$G(X) = f(F_1, F_2, \ldots F_n) \qquad (1)$$

where f( ) = the system model

$F_1, F_2 \ldots F_n$ = input distributions for parameters or variables.

G(X) is defined from the distribution produced from a large number of simulations, i.e., 5000 - 10,000.

Note from Figure 1 that two kinds of inputs are defined - parameters and forcing function values. Model parameters are representations of physical or chemical properties (e.g. soil bulk density, hydrolysis rate constants). Forcing function values correspond to variables or constants that specify conditions or states of the system. In some groundwater transport models such inputs are internally estimated rather than externally derived as shown here.

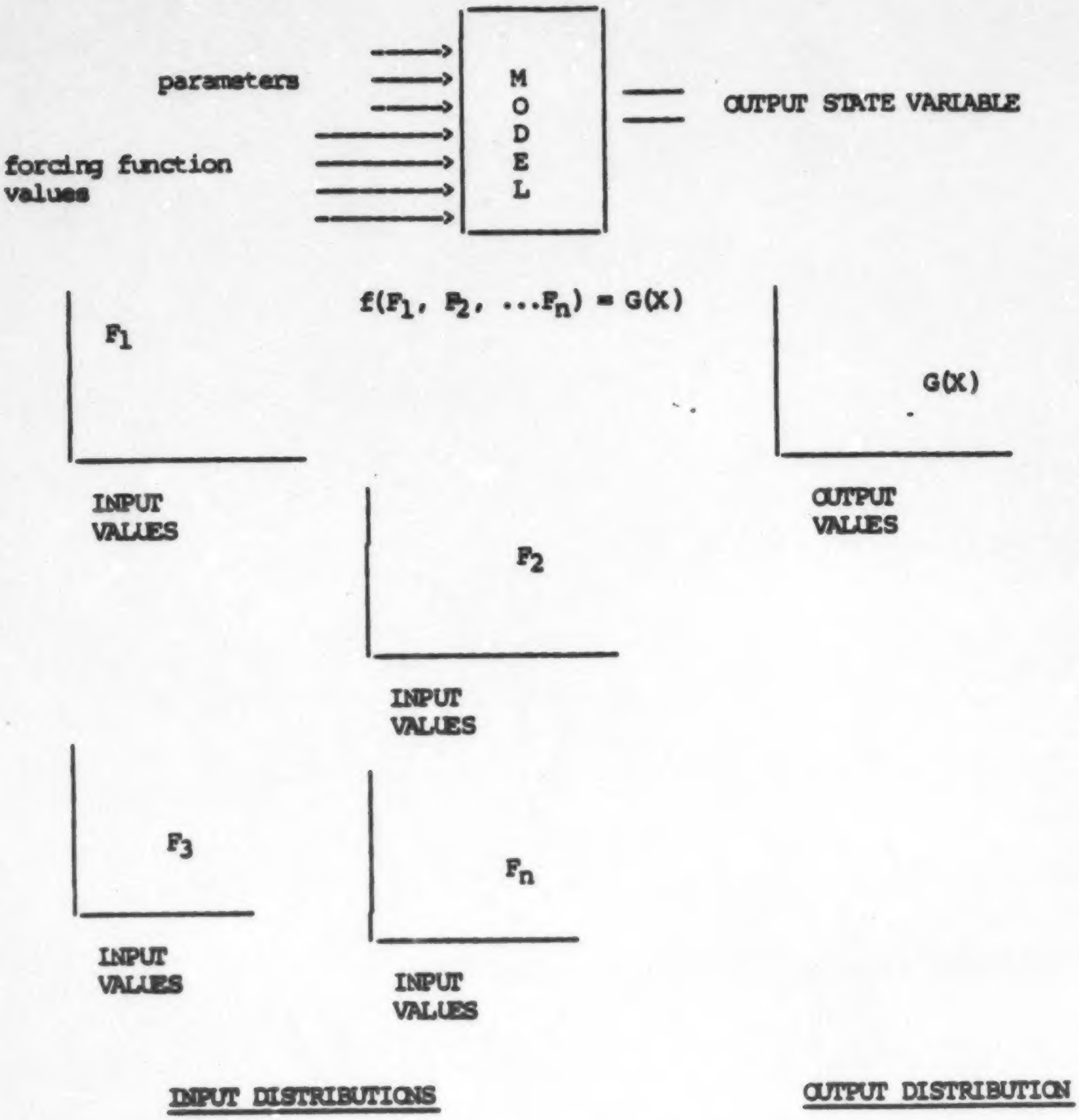

parameters
forcing function values
MODEL
OUTPUT STATE VARIABLE
f(F1, F2, ...Fn) = G(X)
F1
INPUT VALUES
F2
INPUT VALUES
F3
INPUT VALUES
Fn
INPUT VALUES
G(X)
OUTPUT VALUES
INPUT DISTRIBUTIONS
OUTPUT DISTRIBUTION

Figure 1. The Monte Carlo Process for Developing Distributional (Cumulative Frequencies) Results from Models

The monte carlo process proceeds as follows:

- o values from each input distribution are selected at random.
- o a value for the desired output variable, G, is computed for each randomly selected set of inputs
- o the input selection and computation steps are repeated a large number of times, e.g., 5,000
- o the output values are analyzed for presentation as a distribution.

An important point to remember in completing the monte carlo process is the notion that the derived output distribution, G(X), is greatly influenced by the input distributions, $F_1, F_2 \ldots F_n$. This is true even if the system model is known to be a perfectly correct representation of the physical system (i.e., no descriptive uncertainty).

3.2 Model Parameters and Input Data

The groundwater model parameters and input data requirements are given in detail in the mathematical description of the model. The major question for their use in monte carlo analyses is their relationship one to the other. In the simplist case where all input values are independent, the monte carlo process is straightforward. Once each input distribution is developed the process is executed as described. Where inputs are correlated, and therefore dependent, the proper specification of each distribution becomes much more difficult. For example, if F_2 is dependent upon F_1 then F_1 and F_2 have a joint distribution. That is, any value of F_2 is the probability of F_2 given a corresponding value of F_1 (and vice versa). For other situations where dependence exists among more than two variables the problem is further compounded with requirements for joint probability functions. Before developing input data distributions, it is first necessary to determine the existence of any dependence among the data.

Table 1 illustrates the expected dependence among the groundwater model's parameters and input data. This table was constructed from a combination of documented observations and engineering judgement. In some cases very weak dependence may exist but an assumption of independence is acceptable in light of the model's sensitivity to the assumption. The data pairs denoted by D are thought to be sufficiently dependent to require generation of correlated input sequences. All pairs denoted by I are considered independent. The downgradient distance, X will be fixed and thus it can be deleted because it will take on a single, known value.

3.3 Data and Information Sources

The single values or distributions of values for the various input parameters and variables must be developed from data, theoretical constructs, expert judgement or policy considerations. A number of different sources can be used in developing this information including the following:

- the scientific and engineering literature
- laboratory experiments and measurements for specific chemical reactions
- EPA directed surveys
- chemical structure-property correlations and structure-activity relationships
- mathematical modeling

Table 1. Summary of Relationships Among Model Parameters and Input Values

	V	Θ	ρ	α_L	α_T	α_V	X	σ	H	B	f_{oc}	pH	T	k_a	k_n	k_b	k_D
V		D	D	I	I	I	I	D	I	I	I	I	I	I	I	I	I
Θ	D		D	D	D	D	I	D	I	I	I	I	I	I	I	I	I
ρ	D	D		D	D	D	I	I	I	I	I	I	I	I	I	I	I
α_L	I	D	D		D	D	D	I	I	I	I	I	I	I	I	I	I
α_T	I	D	D	D		D	D	I	I	I	I	I	I	I	I	I	I
α_V	I	D	D	D	D		D	I	I	I	I	I	I	I	I	I	I
X	I	I	I	D	D	D		I	I	I	I	I	I	I	I	I	I
σ	D	D	I	I	I	I	I		D	I	I	I	I	I	I	I	I
H	I	I	I	I	I	I	I	D		D	I	D	I	I	I	I	I
B	I	I	I	I	I	I	I	I	I		I	I	I	I	I	I	I
f_{oc}	I	I	I	I	I	I	I	I	I	I		I	I	I	I	I	D
pH	I	I	I	I	I	I	I	I	I	I	I		I	D	I	D	D
T	I	I	I	I	I	I	I	I	I	I	I	I		D	D	D	I
k_a	I	I	I	I	I	I	I	I	I	I	I	D	D		I	I	I
k_n	I	I	I	I	I	I	I	I	I	I	I	I	D	I		I	I
k_b	I	I	I	I	I	I	I	I	I	I	I	D	D	I	I		I
k_D	I	I	I	I	I	I	I	I	I	I	D	D	I	I	I	I	

D denotes dependence

I denotes weak or no dependence

The required data can be further characterized according to type. That is, data that describe pollutant transport, data that characterize the environment, and data that characterize the individual chemicals. The major data influencing transport are flow velocity, V, and dispersivities α_L, α_T, and α_V. Flow velocities for various sites have been reported in the literature and were included in the EPA survey of Part B permit applications. In many cases velocities can be estimated using a relationship incorporating Darcy's law when the gradient, hydraulic conductivity, and porosity are known. Similarly, dispersivities have been reported for a number of case studies and recent research has defined both empirical and theoretical methods for relating dispersivities to other system properties.

Environmental characterization data can be developed from national data bases. For example, many groundwater pH and temperature measurements are recorded as entries to the EPA STORET data base. Another source is the EPA survey of Part B permit applications for bulk densities (ρ), porosities (θ), and facility geometries (related to σ). The literature reports individual values and ranges of values for these and other parameters including organic carbon content, foc. The parameter most closely related to the performance of the engineered components of land disposal is sigma, σ. In this case almost no data from case studies are available but expert judgement enhanced by modeling can be used to generate appropriate values.

Chemical-specific data can be derived from the literature, generated by specific laboratory experiments, or estimated from theoretical or empirical relationships. In some cases useful qualitative information can be generated by expert judgement. Most notable is judgement on the existence of hydrolyzable functional groups for each compound. Expert judgement can determine for many chemicals if hydrolysis will degrade the chemical. The assignment of a zero rate constant for non-hydrolyzable chemicals allows the analysis to proceed without the need for experimental data. In other cases structure--activity relationships can be used to estimate needed parameters. For example, the octanol-water partition coefficient can be reliably estimated from knowledge of molecular structure. The proper interpretation of data generated from the above methods. This can be addressed by convening expert panels to review reported data, specify limits of uncertainty, and delineate appropriate ranges of application.

3.4 Data Generation Procedures

The input data and parameters listed in Table 1 must be generated before monte carlo analyses can proceed. It is convenient to separate this activity into two tasks: generating independent data sets; and generating correlated or dependant data sets. Independent data sets can be developed as empirical distributions of observed data, as theoretical distributions from a "best-fit" analyses of observed data, or as assumed distributions. Dependant data sets can be developed as empirical, joint, or multivariate distributions, theoretical distributions, or from functional dependencies among the variables and parameters.

3.4.1 Independant Parameters and Variables

The summary shown in Table 1 suggests that none of the variables or parameters is totally independant from all other variables or parameters. In some cases, however, an independent "seed" distribution can be generated to which other variables are correlated. For example, the temperature (T) will influence the hydrolysis rate constants (k_a, k_n, k_b) but the reverse is not true nor for the system studied does anything else influence temperature. Thus temperature distributions can be developed as an independent variable. Following this rationale, the parameters and variables to be generated independently are as follows:

B - the thickness of the saturated zone

foc - the fractional organic carbon content of the soils

pH - the groundwater hydrogen ion activity

T - the groundwater temperature

H - the leachate penetration depth into the saturated zone

The thickness of the saturated zone, B, influences the opportunity for vertical dispersive mixing as the plume moves down gradient. Literature values taken from measurements and surveys were used to derive a distribution for this parameter.

The fractional organic carbon content, foc, is used to determine the distribution coefficient, K_D. Recall from the groundwater model description that

$$K_D = foc\ Koc \tag{2}$$

where Koc = distribution coefficient normalized to organic carbon. It is clear from this relationship that the variation in foc leads directly to variation in the K_D and hence retardation of the solute in groundwater. Unfortunately, few if any comprehensive subsurface characterizations of organic carbon content exist. In general the values are known to be very low, typically less than .01. In the absence of evidence to the contrary the approach taken was to assume a low range of foc. A distribution shape for this range was determined by the distribution of measured dissolved organic carbon recorded as entries to STORET. The assumption is that dissolved organic carbon reflects the existence (and hence distribution) of organic carbon in the subsurface environment being considered.

The model assumes that the groundwater is sufficiently buffered to insure that the pH is not influenced by input of contaminants or changes in temperature. This permits a pH distribution to be derived independently. STORET data were analyzed, a distribution developed and summary statistics generated for pH.

Assumptions about the independence of groundwater temperature are essentially the same as for pH. Temperature influences hydrolysis reactions but the reverse is ignored. Actually, temperature can also influence sorption but such effects are ignored in this analysis.

The depth, H, to which the leachate flow penetrates the saturated zone is probably related to the relative differences in the leachate velocity and the groundwater velocity. Because disposal of free liquids is not permitted, density gradients or stratification of "floaters" or "sinkers" are not likely to occur. Lacking any meaningful data, a simple, independent, uniform distribution ranging from a fixed minimum to a fixed maximum was used.

A summary of the procedures used to generate the independent input data sets is given in Table 2. The fitted distribution (FD) method refers to the development of a mathematically-defined frequency distribution function by "fitting" various possible distributions (e.g., normal, log normal, exponential) or mixtures of distributions to the "observed" data and selecting the "best fit" distribution for use in the monte carlo process. The distributions selected for each variable or parameter are given in section 4.0 of this report. Inall cases we recognize the possibility that the data in STORET may represent a biased sample. However, lacking a better alternative the data were accepted as representative of groundwater and subsurface conditions.

Table 2. Summary of Procedures Used to Generate Independent Input Data Sets

Input Data	Method of Generation	Source of Data and/or Reference
B	FD*	Various literature
F_{oc}	FD	STORET, assumptions
pH	FD	STORET
T	FD	STORET
H	AD**	—

*fitted distribution to empirical data

**assumed distribution

3.4.2 Dependent Parameters and Variables

The remaining input parameters and variables are dependent and cannot be generated without properly "matching" each value with other related values. Recall that our objective is to provide a consistent set of data that when viewed as descriptions of site-specific scenarios will produce situations that occur in nature. The main purpose of building in dependencies is to avoid unrealistic or impossible sets of data. For example, a uniform soil having high porosity because of high clay content will rarely if ever have high groundwater velocities because of the low hydraulic conductivities. Failure to exclude such possibilities however by assuming that porosity and velocity are independent will lead to unrealistic if not incorrect modeling results.

The "consistency" criterion intended here needs further elaboration. In general, precise functional relationships among all the dependent variables or parameters do not exist. Similarly, observed data for all values taken in sets do not exist or are inadequate in number to permit a statistical representation of the dependencies. Fortunately, however, equations do exist in the engineering and scientific literature to permit generation of sets of "possible" combinations of input data. Generation of consistent sets of input data is much easier to accomplish than the more rigorous but related task of predicting a precise, site-specific set of values given only one or two measurements at that site. The parameters and variables to be generated as dependent values are as follows:

$\alpha_L, \alpha_T, \alpha_V$ = dispersivities in the longitudinal, lateral, and vertical directions assumed to be largely dependent on distance, x

θ = porosity of the soil or porous media is assumed to be largely dependent on soil properties including particle sizes textural classes, bulk densities, and parent material

ρ = bulk density of the soil or porous media is assumed to be largely dependent on soil properties including porosity

V = groundwater flow velocity is assumed to be largely dependent on soil properties including hydraulic conductivities, porosity, bulk density and on hydraulic gradient (groundwater slope)

σ = the standard deviation of the gaussian distribution representation of the source concentration is related via mass balance principles to leachate volumes, groundwater velocity, porosity, and depth of leachate penetration into the saturated zone

k_a, k_n, k_b = hydrolysis rate constants are assumed to be largely dependent on groundwater pH and temperature and on specific chemical properties

k_D = effective distribution coefficient for each specific chemical is assumed to be largely dependent on the organic carbon content of the soil or porous media and in some cases on the pH as well as on specific chemical properties of the pollutant

3.4.2.1 Dispersivity

The "spreading" of solutes transported by groundwater is usually described as a combination of molecular diffusion and mechanical mixing. The relative magnitudes of each are such that molecular diffusion can be ignored. The property of the soil or porous medium that is commonly used to define the magnitude and direction of dispersion is included in the dispersivity parameters. A generalized theory to describe dispersivity has not yet been developed but recent work has noted a strong dependence on scale (Sudicky et al., 1983; Anderson, 1979; Pickens and Grisak, 1981; Pickens and Grisak, 1981; Molz et al., 1983; Gelhar et al., 1985). Some investigators (Pickens and Grisak, 1981) have reported simple, linear dependencies for longitudinal dispersivity, α_L, as

$$\alpha_L = 0.1 X \qquad (3)$$

where X = mean travel distance

More recently Guven et al. (1984) completed a detailed theoretical analysis and suggested an expression of similar form

$$\alpha_L = 0.093 X + 0.007 \text{ (X in meters)} \qquad (4)$$

Many experimental data suggest that equation 3 is a reasonable approximation for α_L given our limited objective of "consistency" in the input data set.

Transverse dispersivity, α_T, has been studied to a lesser degree but its magnitude is known to be less than longitudinal dispersivity while maintaining scale dependency (Santy, 1980; Anderson, 1979; and Sudicky et al., 1983). Typically, α_T is related to α_L by a simple ratio leading to the following expression

$$\alpha_L/\alpha_T = LTR \tag{5}$$

where LTR = longitudinal-transverse dispersitivity ratio

A range of LTR's has been reported and appears to center around a value of 3.0. Again, to insure consistency in input data while maintaining a straightforward approach, an LTR of 3.0 was selected for the monte carlo analysis.

For unidirectional flow in the longitudinal direction the vertical dispersivity, α_V, is quite low. Using the ratio, α_L/α_V, to describe vertical dispersivity, Gelhar et al., 1985, reported a range of 30-1860 with an average of about 400. Because of the uncertainty surrounding proper specification of values for vertical dispersivity, it is varied uniformly from 40 to 400 m in the monte carlo routine.

The data generation approach for dispersitivity can be summarized by the following equations:

$$\alpha_L = 0.1\ x \tag{6}$$

$$\alpha_T = 0.0333\ x \tag{7}$$

$$\alpha_V = 0.0025(x)\ -\ 0.01(x) \tag{8}$$

where x is the downgradient exposure point distance selected for implementation of the decision rule.

3.4.2.2 Porosity

The porosity, θ, of a uniform porous media is largely a function of particle size. For small particle sizes like clay, porosity increases to a maximum of around 50%. Porosities of coarser media like gravel decrease to a minimum of around 30%. These measured ranges of porosities suggest a strong correlation with mean particle diameter, d. Data reported by Davis (1969) were used to develop a regression equation relating porosity to d as follows

$$\theta = 0.261 - 0.0385 \ln d \qquad (9)$$

Because porosities are generally known for a wide range of soils and porous media another approach to generating input values is to determine a distribution for θ from observed data. It will be shown later, however, that θ is linked to velocity, V, through the mean particle size, d. Thus, to preserve this relationship, the distribution for θ is generated from a "seed" distribution for d via equation 9. The mean plarticle diameter as the single correlated property to porosity ignores the influence of particle sorting within porous media and hence may not be the most accurate approach in developing the dependence. Unfortunately, at the present time the distribution of sorting and mean particle size in materials in the saturated zones is not well enough known to be used in the methodology.

The distribution of particle sizes selected for this study should reflect the distribution of subsurface characteristics in all areas subject to potential use for land disposal. While specific case studies exist, apparently no general characterization is available. One approach is to assume a distribution bounded by reported ranges. In the absence of data both a uniform and a log-uniform distribution were investigated. As will be shown later, the log-uniform distribution was selected because it more heavily weights the influence of smaller particle sizes and because the related, derived velocity distribution is more consistent with observed data.

3.4.2.3 Bulk Density

The soil's bulk density, ρ, is defined as the mass of dry soil divided by its total (or bulk) volume. Bulk density directly influences the retardation of solutes and is related to soil structure. In general, as soils become more compact their bulk density increases. This relationship produces a dependency between porosity, θ, and ρ. Freeze and Cherry (1979) note that

$$\theta = 1 - \frac{\rho}{\rho_p} \qquad (10)$$

where ρ_p = particle density, g/cm^3

By assuming $\rho_p = 2.65$, equation 10 can be rearranged to yield an expression for estimating ρ given θ as follows

$$= 2.65\ (1-\theta) \qquad (11)$$

The particle density of soil materials varies over a very narrow range and can be fixed at a value of 2.65 gm/cm^3. Equation 11 can be used to derive a frequency distribution for   given the previously generated distribution for θ.

3.4.2.4 Velocity

The velocity of groundwater is a major determinant of the transport of solutes in subsurface systems. In uniform porous media it is the dominant factor and must be properly specified in the monte carlo process. Dependencies among the input data (θ and ρ) must be preserved while generating realistic values of velocity.

Groundwater flow velocities vary widely. Mackay et al. (1985) report that velocities typically range between 1-100 m/yr. These ranges apply to typical "natural gradient" conditions and higher velocities can exist under both man-induced (e.g., well-field drawdown) and extreme natural situations. For example, velocities in excess of 9000 m/yr have been reported (Guven et al., 1984) for a glacial outwash material. Such data sources could be used to develop an empirical frequency distribution for velocity but the requirement to maintain dependancies with soil properties is not easily met using this approach. The EPA survey of Part B permit applications for velocity could be used to generate empirical distribution, but in addition to the dependency problem just described, this limited sample is likely to be biased.

Velocities are related to soil properties and other site-specific factors through Darcy's law. Using Darcy's law and assumptions of steady flow in uniform, saturated media yields the following expression for average pore velocity, V

$$V = \frac{K_s\ S}{\theta} \tag{12}$$

where K_s = saturated hydraulic conductivity, cm/sec

S = hydraulic gradient

Because an expression for porosity, θ, has already been developed, equation 12 properly relates V and θ. The saturated hydraulic conductivity, K_s, reflects the "ease" with which water is transported through porous media and for any given fluid K_s is a function of porous medium properties such as particle size, grain shape, connectivity, and tortuosity. To the extent that K_s is related to such properties if functional relationships exist for K_s then dependencies among V, K_s and θ can also be represented.

Individual, site-specific measurements for K_s are usually difficult to make and the spatial variability of "point" measurements is the subject of much current research. Also, site-specific variations in K_s values introduce considerable uncertainty in modeling groundwater flow when point estimates or averaged point values are used as model inputs. Recall that the objective here is to insure consistency in results while representing the wide variations expected from site to site. Given this objective (that is much less demanding than an attempt to predict an accurate K_s for any given site), it is reasonable to use an approximate functional relationship. The most notable among these is the Karmen-Cozeny equation (Bear, 1979),

$$K_s = 478 \left[\frac{\theta^3}{(1-\theta)^2} d^2\right] \qquad (13)$$

where θ = porosity

d = mean particle diameter

Note that equation 13 relates K_s to θ and d. Furthermore, θ is derived from d that is generated from a "seed" distribution.

The remaining factor in equation 12 for velocity is the gradient, S. In general the gradient is a function of the local topography, groundwater recharge volumes and locations, and the influence of withdrawals (e.g., well fields). It is also likely to be indirectly related to porous media properties. Rarely are large gradients associated with very high conductivities. No functional relationships exist, however, to express this association. Thus, another independent "seed" distribution is required. The potential problem with the independence assumption is in "extreme" values. Data sets having large values for both K_s and S will also have very large values for velocities resulting in unrealistic conditions. Such condition can be prevented by bounding the velocities such that a fixed maximum is not exceeded. The observed value of 9250 m/yr was selected for this purpose.

The distribution for the gradient can be assumed or derived from observations. Gradient data were included in the EPA survey of Part B permit applications and were analyzed to develop a frequency distribution. Results are given in later sections of this report.

3.4.2.5 Standard Deviation of the Gaussian Distrubtion for the Source Concentration

The parameter defines the nature of the leachate after it has mixed with the underlying saturated zone. Because sigma reflects the nature and extent of the leachate interaction with the groundwater beneath the facility, it and hence also reflects the failure of the engineered controls on the facility (e.g., liners, caps). From mass balance principles is related to the environmental setting by

$$\sigma = q A_w C_L \Big/ \sqrt{2\pi}\ V \theta H C_o \tag{14}$$

where q = unit areal flux of leachate through the land disposal facility, m yr^{-1}

A_w = area of disposal facility, m^2

V = groundwater velocity, m yr^{-1}

θ = saturated zone porosity

H = leachate penetration into the saturated zone, m

C_L = contaminant concentration in the leachate

C_o = contaminant concentration in the mixing zone beneath the facility

If we assume that the leachate concentration, C_L, is the same as the maximum concentration C_o (at y = 0) of the gaussian concentration distribution, then equation 14 enables direct calculation of σ given the other, known variables. Setting $C_L = C_o$ in equation 14 simply means that the leachate displaces the groundwater and dilution occurs after advective transport is initiated; a reasonable assumption given the low velocities for leachate fluxes.

Values for q vary depending on the location of facilities, their vertical configuration (e.g., liners, caps), and their performance over time. The procedure used to produce a distribution for q is described in the E. C. Jordan (1985) report. A distribution was generated from the EPA survey of Part B permit applications for the area term, A_w. Velocity, V, and porosity, Θ, and penetration depth, H, are generated as previously discussed. For mathematical reasons (boundary effects) the constraint that the ratio, H/B, where B is the saturated zone thickness, be less than 0.5 must also be made. The minimum saturated thickness is 3 meters.

3.4.2.6 Hydrolysis Rates

Hydrolysis rate constants are unique to each chemical and will be determined from the literature or from laboratory experiments. All rates (acid-catalyzed (k_a), neutral (k_n), base-catalyzed (k_b) are influenced by groundwater temperature. k_a and k_b are also influenced by pH. The pH dependency is included directly in the groundwater model and the rates will be adjusted accordingly via the independently derived distribution for pH. The temperature dependency requires further elaboration.

Rate constants are often adjusted for temperature effects by the Arrhenius equation. Because the rate constant values are given for a specific temperature, the need exists to adjust these values to account for different temperatures in the groundwater. Using the generic activation energy recommended by Wolfe (1985) of approximately 20 k cal/mole, the temperature correction factor can be written as

$$\frac{k^{T}_{a,n,b}}{k^{Tr}_{a,n,b}} = \exp\left[10^4\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \qquad (15)$$

where $k^{T}_{a,n,b}$ = second-order hydrolysis rate constants for acid, neutral, or base conditions at temperature T

$k^{Tr}_{a,n,b}$ = second-order hydrolysis rate constants for acid, neutral, or base conditions at reference temperature, T_r

T, T_r = temperature, °Kelvin

The temperature can also influence the base-catalysed hydrolysis rate through influence on autoprotolysis of water. Porous medium properties and groundwaters are sufficiently buffered, however, to minimize this effect. Temperature corrections to pH are not made.

The measurement and extrapolation errors for hydrolysis mesurements are not yet fully developed. Once the experimental program to develop such values is fully implemented the nature and magnitude of these errors will be included.

3.4.2.7 Distribution Coefficient

The relationships most suited for relating the chemical distribution coefficient, K_D, to soil or porous medium properties are discussed in detail by Karickhoff (1985). In cases where reliable relationships do not exist, measurements are required. For many cases hydrophobic binding dominates the sorption process and it is possible to relate the distribution coefficient directly to soil organic carbon. For these cases the dependency is given by

$$K_D = K_{OC} f_{OC} \qquad (16)$$

where K_{OC} = normalized distribution coefficient for organic carbon

f_{OC} = fraction organic carbon

Recall that f_{OC} values will be generated as an independent parameter as previously described. Equation 16 will be used to preserve dependency between porous media properties and chemical sorptive properties. For other binding mechanisms described by Karickhoff (1985) including those for polar, ionizable compounds adjustments will be made on a case-by-case basis as appropriate.

4.0 Data Generation Results

The combination of data sources and approaches described in Sections 3.3 and 3.4 were used to generate input frequency distributions for each of the parameters and forcing function variables. In some cases intermediate or precursor variables were also generated to enable representation of appropriate dependencies among the variables and parameters. Results for these variables are also included in this section. Table 3 gives a summary of the distribution types and parameters for each model parameter or variable. For derived distributions, only the mean and range of the synthesized data are given--it's not necessary to approximate these results by a mathematical distribution function. In some cases only single, fixed values were selected largely based upon their nature (e.g., a chemical-specific rate constant) or upon policy directions (e.g., the downgradient distance, x).

Table 3. Summary of Results for Input Data Generation

Parameter or Variable	Distribution Type	Distribution Parameters		Range
		mean	std. dev.	min-max
Temperature, °C	Normal	14.4	5.29	(0.0 - 30.0)
pH	Normal	6.2	1.28	(0.3 - 14.0)
Dissoloved Organic-C, mg/1	Lognormal	1.99	1.09	(0.01 - 6.89)
f_{oc}	Lognormal	-5.76	3.17	(.001 - .01)
d, cm	Log_{10}uniform	.0063	—	(.0004 - 0.10)
θ, cm^3 m^{-3}	derived from d			(.30 - .56)
ρ, gm cm^{-3}	derived from θ			(1.16 - 1.8)
K_s, cm sec^{-1}	derived from θ, d			(.0001 - .48)
S	exponential	.0309	—	(.00001- 0.10)
V, myr^{-1}	derived from S, K_s, θ			(.01 - 9250)
B, m	exponential	78.6	—	(3.0 - 560)
A_w	mixed;exponential uniform			(23 - 930,000)
H, m	derived from uniform	6.0	—	(2.0 - 10.0)
q, m	modeling			(0.0 - .3)
σ, m	derived from q, A_w, V, H, θ			(.001 - 60,000)
α_L, m	single values			
α_T, m	single values			
α_V, m	single values			
X, m	single values			
k_a MM^{-1} yr^{-1}	chemical specific value			
k_n yr^{-1}	chemical specific value			
k_b MM^{-1} yr^{-1}	chemical specific value			
k_D	chemical specific value			

4.1 Fraction Organic Carbon Content, f_{oc}

Recall from Section 3.4.1 that f_{oc} was generated by assuming a fixed, low range of .001 - .01 and using the observed distribution of dissolved organic carbon, DOC, to "shape" the f_{oc} distribution. This was done by assuming both variables had identical distributions and scaling the f_{oc} by the coefficient of variation (CV) for the DOC. That is, the mean value for f_{oc} (based upon a lognormal distribution with a stated range) was multiplied by the DOC coefficient of variation to yield a standard deviation for the f_{oc}. This fully specified the distribution.

4.2 Mean Particle Size, d

The distribution of d should correspond to the distribution of soil types in the saturated zones across the country. As previously discussed such a charactization does not exist and the mean values alone do not describe sorted grain sites. Following the rationale developed in Section 3, the $\log_{10}$ uniform distribution was assumed. This distribution, shown in Figure 2, is bounded over the range from .0004 cm, corresponding to a clay material, to 0.1 cm, corresponding to a gravelly sand. The mean is .0063 cm corresponding to a soil somewhat finer than a silty fine sand but coarser than a clayey sandy silt. This assumed distribution is a key component of the input because it influences Θ and V. As will be shown the $\log_{10}$ uniform distribution produces subsequent distributions for V that are more consistent with observed data than alternative assumed distributions investigated. Clearly, however, this is an area that should be more fully investigated.

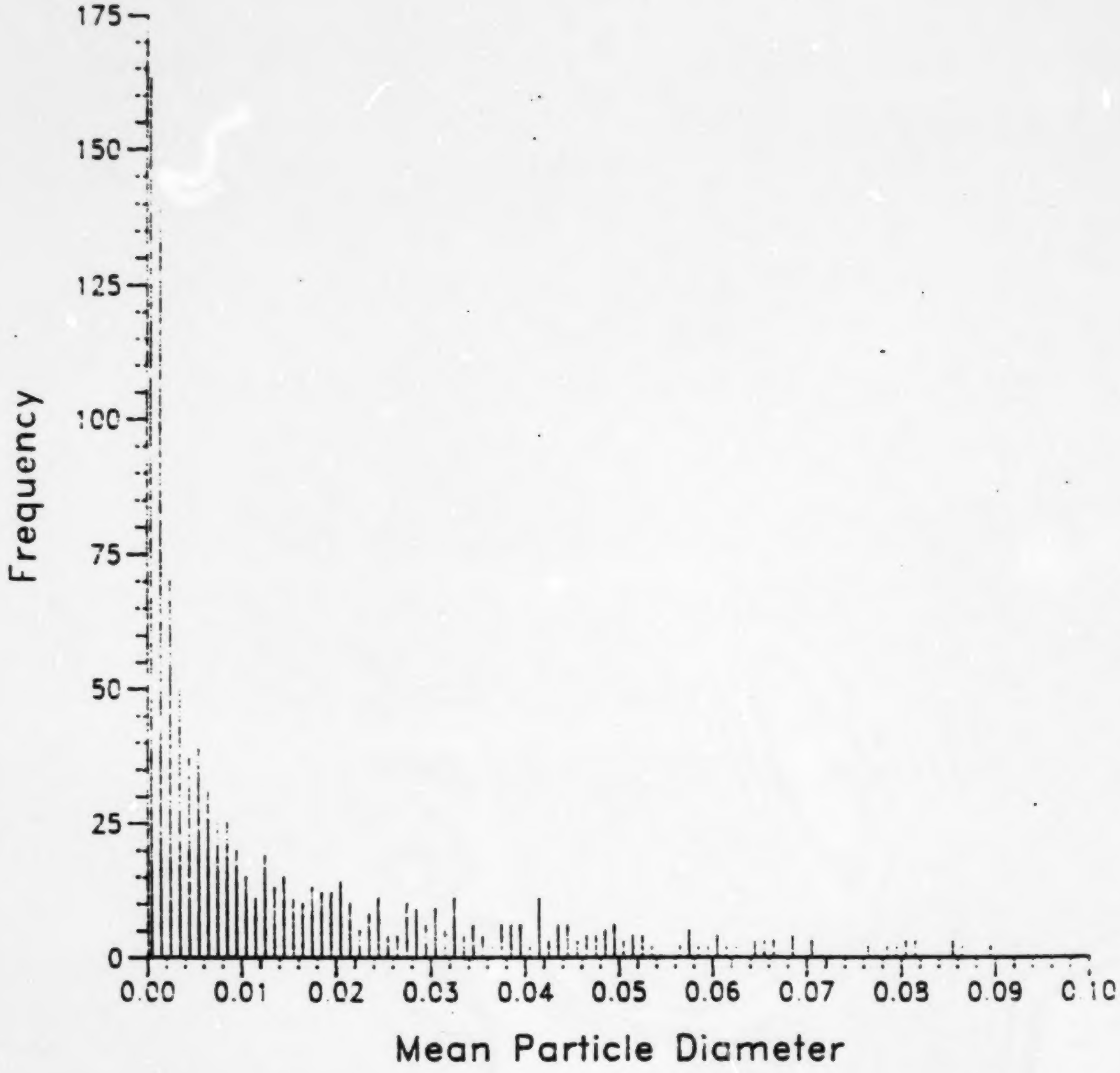

Frequency
175
150
125
100
75
50
25
0
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
Mean Particle Diameter

FIGURE 2

4.3 Porosity (θ), Bulk Density (ρ), Hydraulic Conductivity (K_s) and Gradient (S)

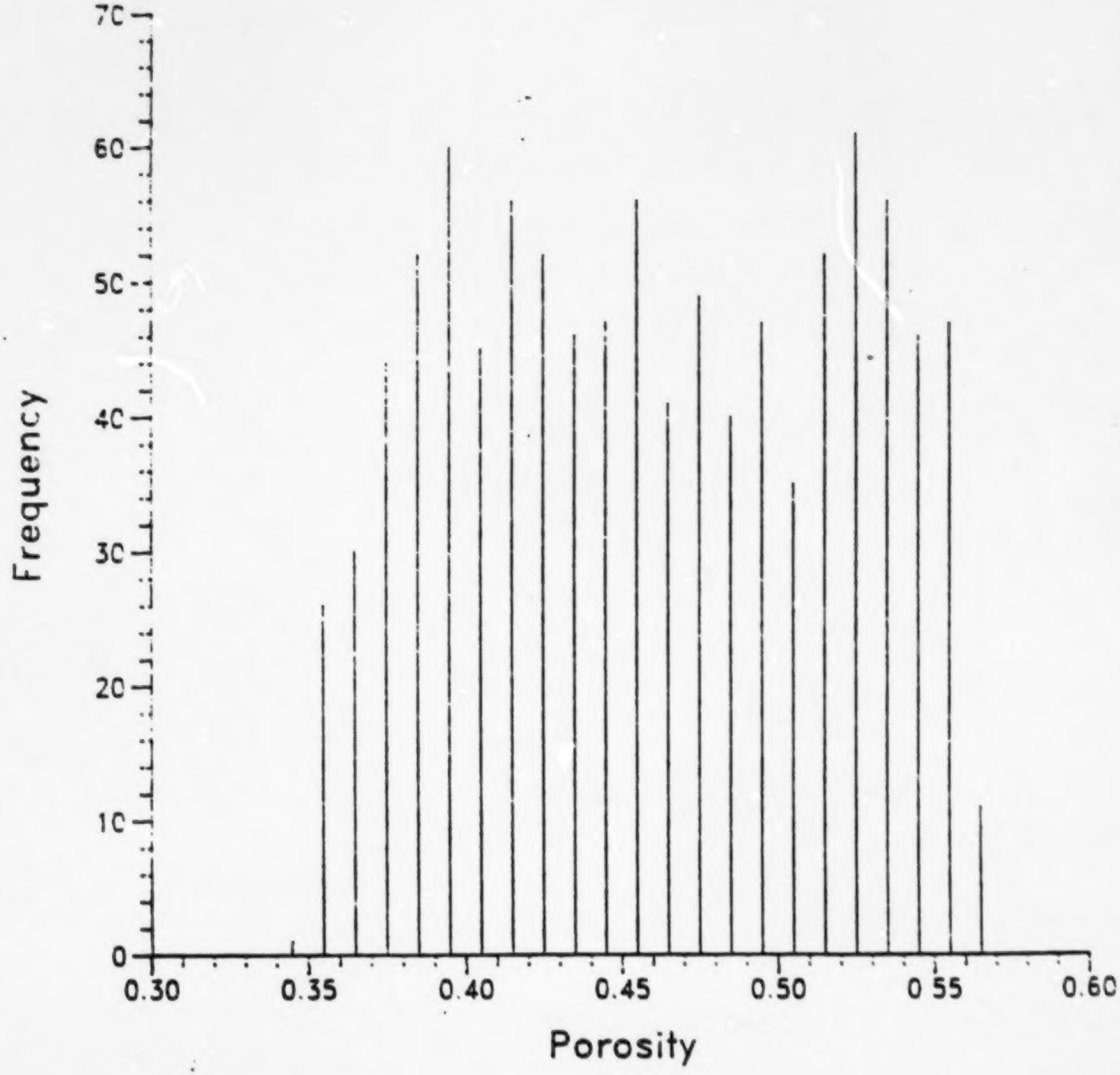
Graphical representations of frequency distributions for each of these parameters are given in Figures 3-6. Only one distribution, S, required a mathematical description since each data point for all others in this group was derived through functional relationships with mean particle size, d.

4.4 Saturated Zone Depth (B), and Facility Area (A_w)

The graphical representations for these fitted distributions are shown in Figures 7 and 8. Because A_w is used in developing for "engineered" facilities, Figure 8 applies only to landfills. The rationale for this approach is the requirement that impoundments must be "closed" as if the system were a landfill.

4.5 Percolation Flux (q) and Initial Concentration Standard Deviation (σ)

The distribution for q is described in the E. C. Jordan report (1985). Because a relatively few data points make up this distribution a direct interpretation from the data expressed as a cumulative frequency table was made. That is, linear interpolation for intermediate data points on the Figure 9 developed in the E. C. Jordan report (1985) was employed. Subsequent generation of the distributions for A_w, H, V, and σ produced Figures 10-12.



Frequency
0
10
20
30
40
50
60
70
0.30
0.35
0.40
0.45
0.50
0.55
0.60
Porosity

FIGURE 3

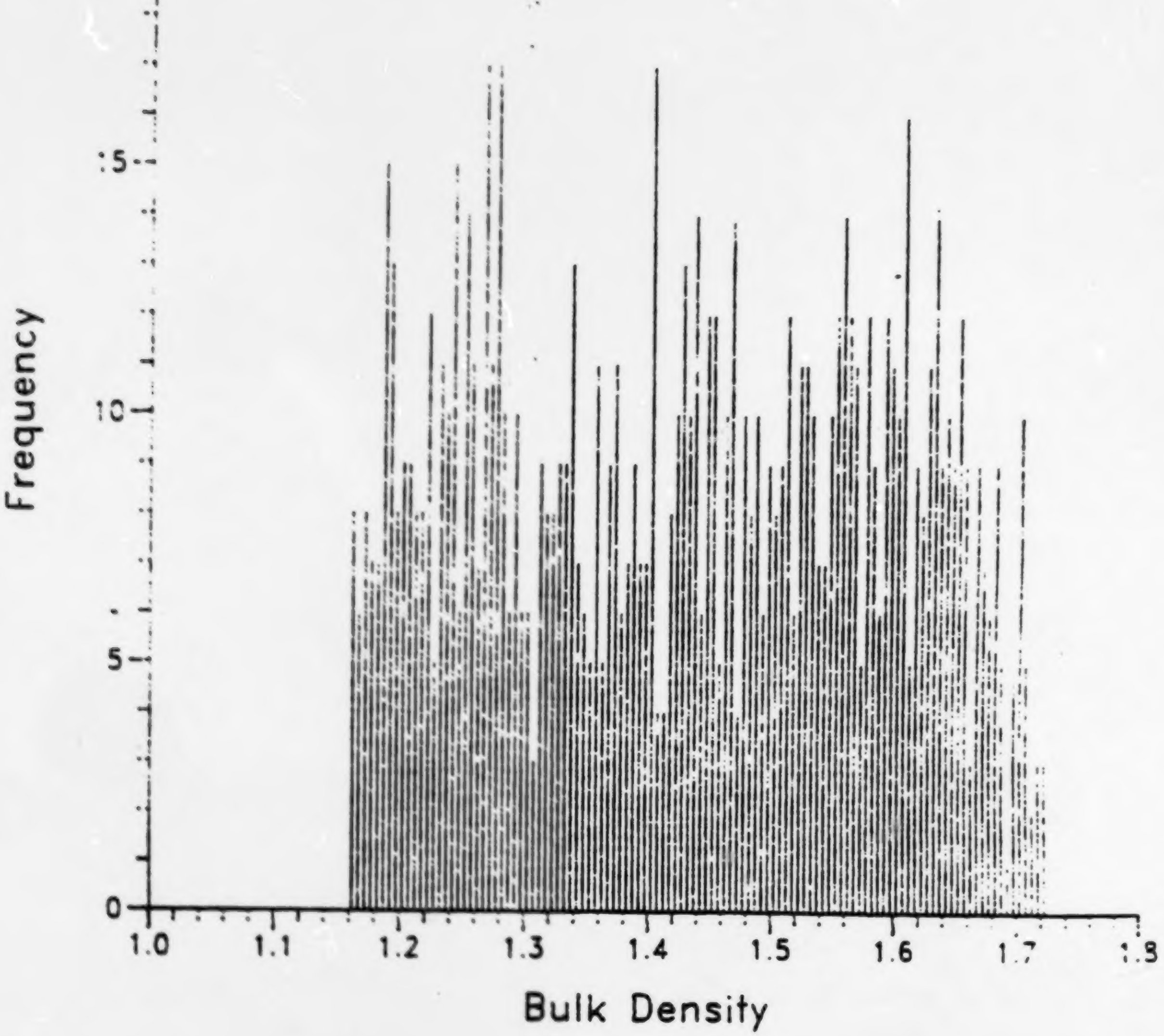
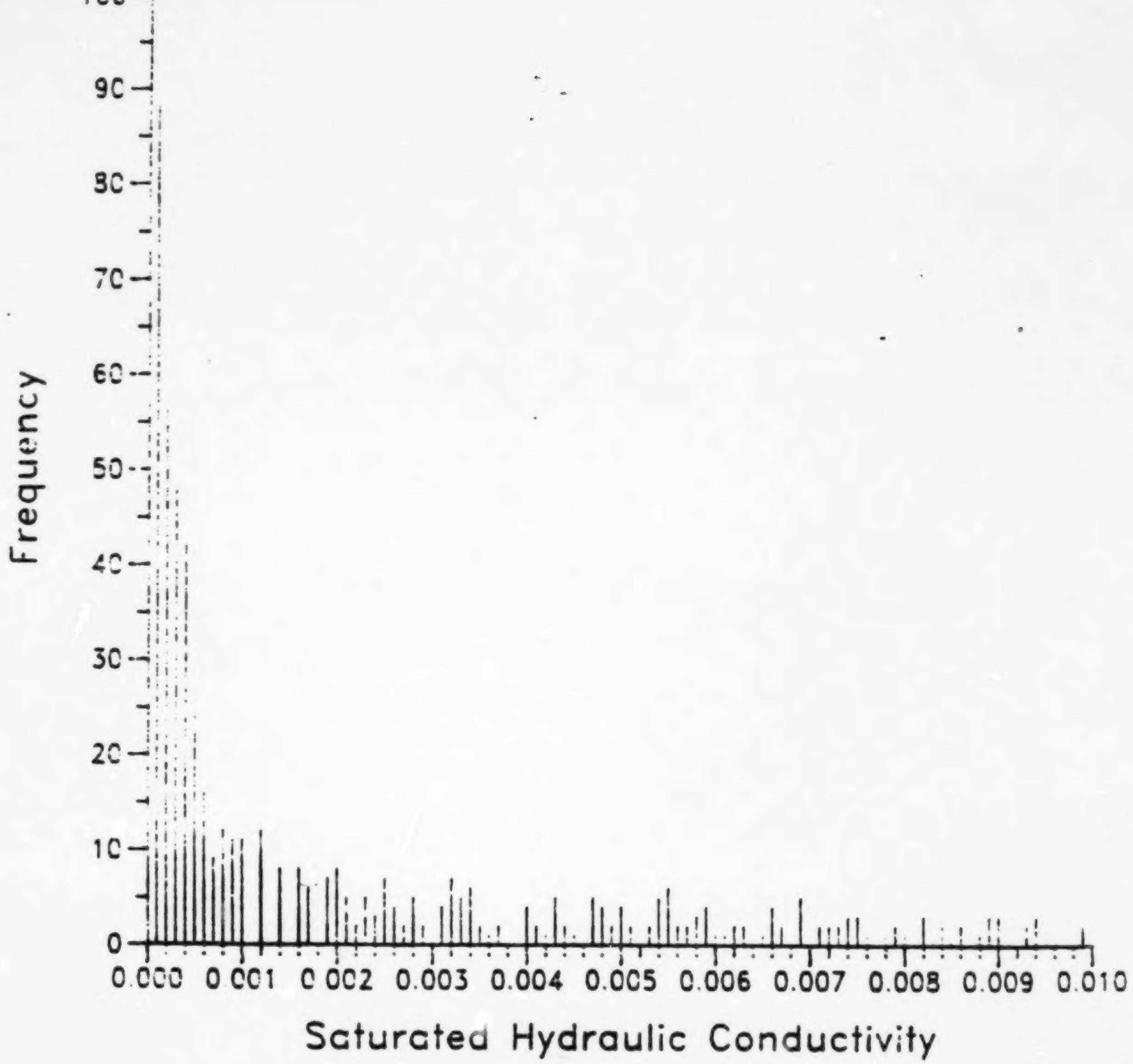
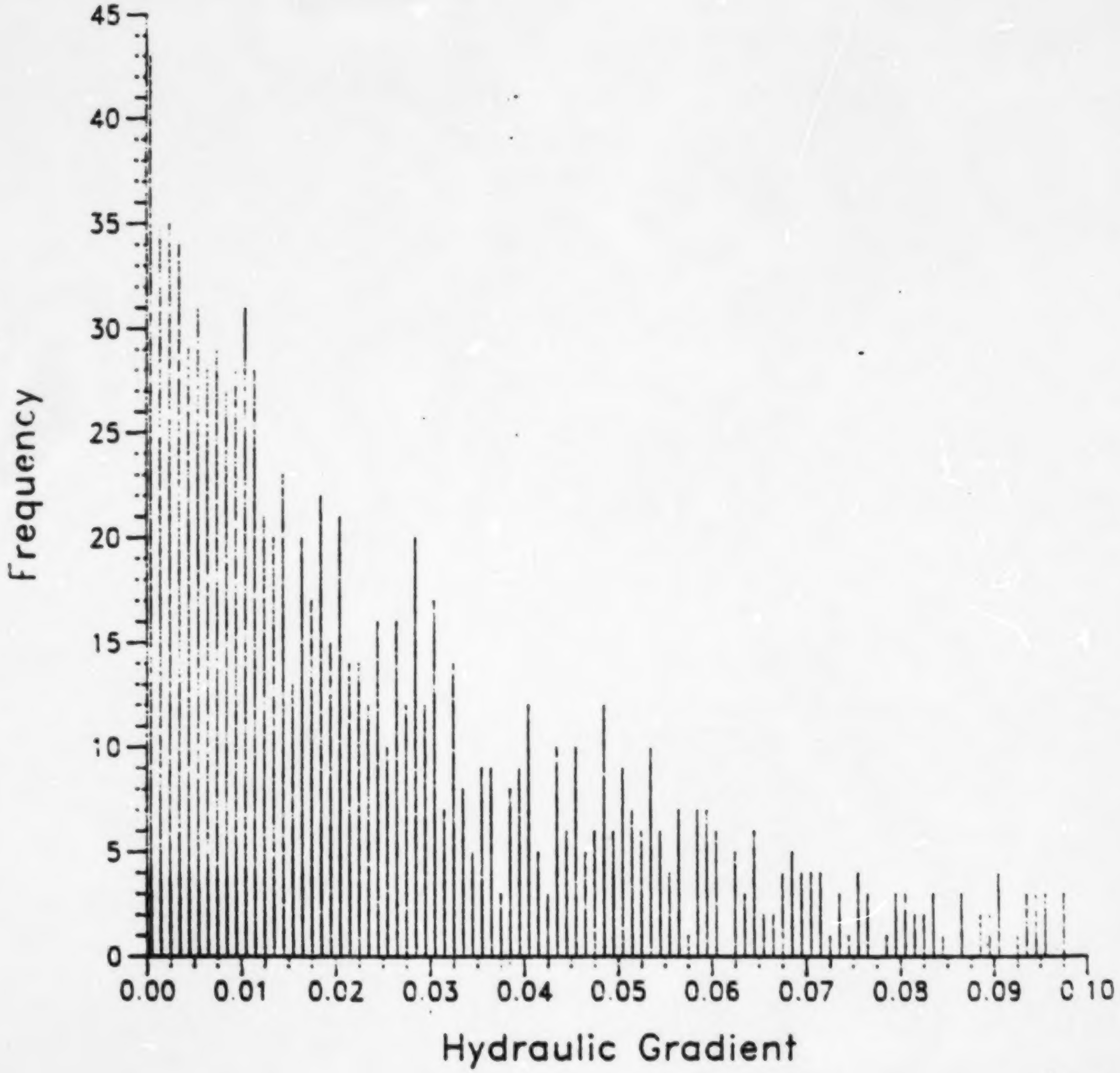


FIGURE 4



Frequency
100
90
80
70
60
50
40
30
20
10
0
0.000
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.010
Saturated Hydraulic Conductivity

FIGURE 5


Frequency
45
40
35
30
25
20
15
10
5
0
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
Hydraulic Gradient

6

FIGURE 6

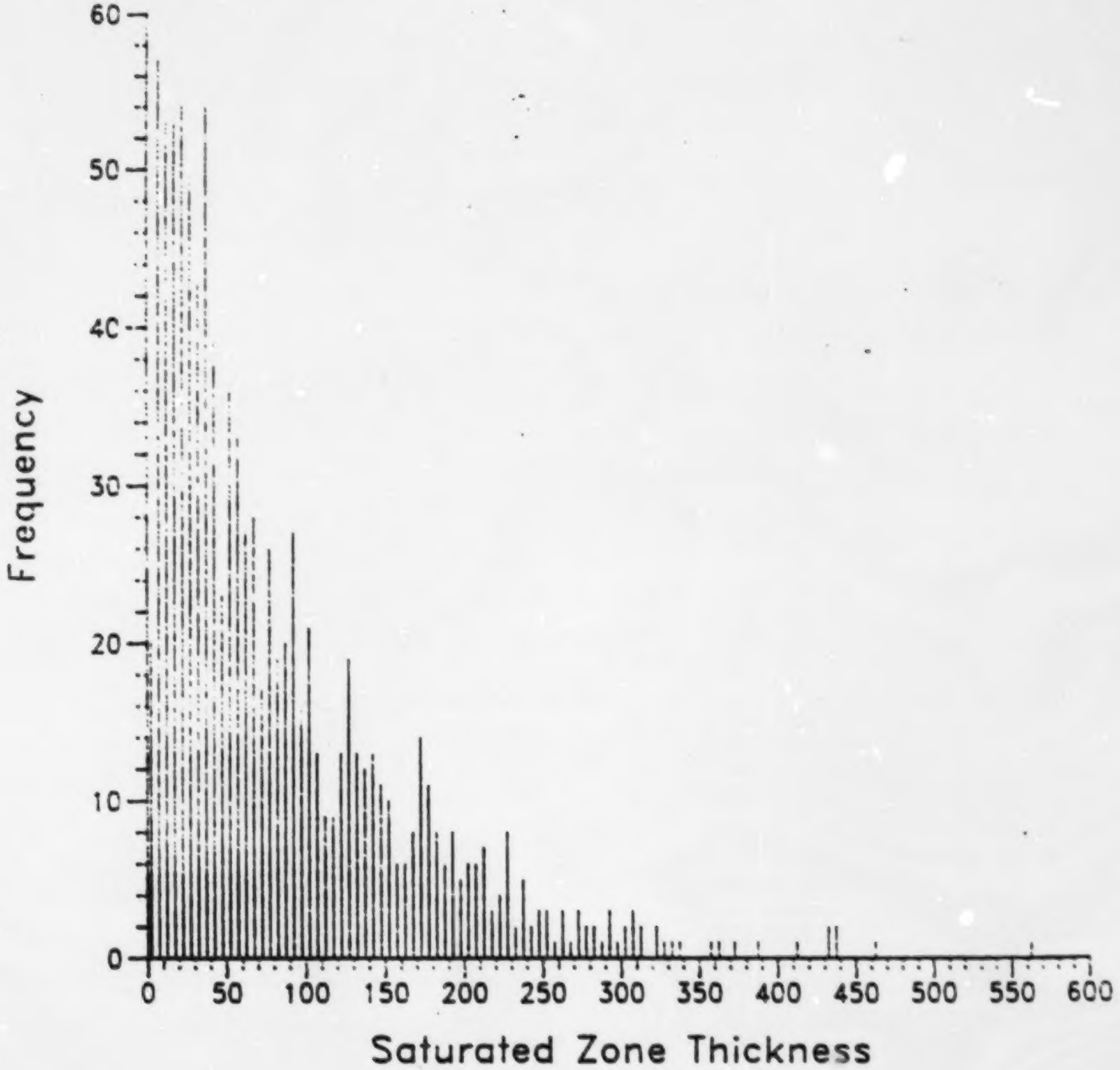

Frequency
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
400
450
500
550
600
Saturated Zone Thickness

FIGURE 7

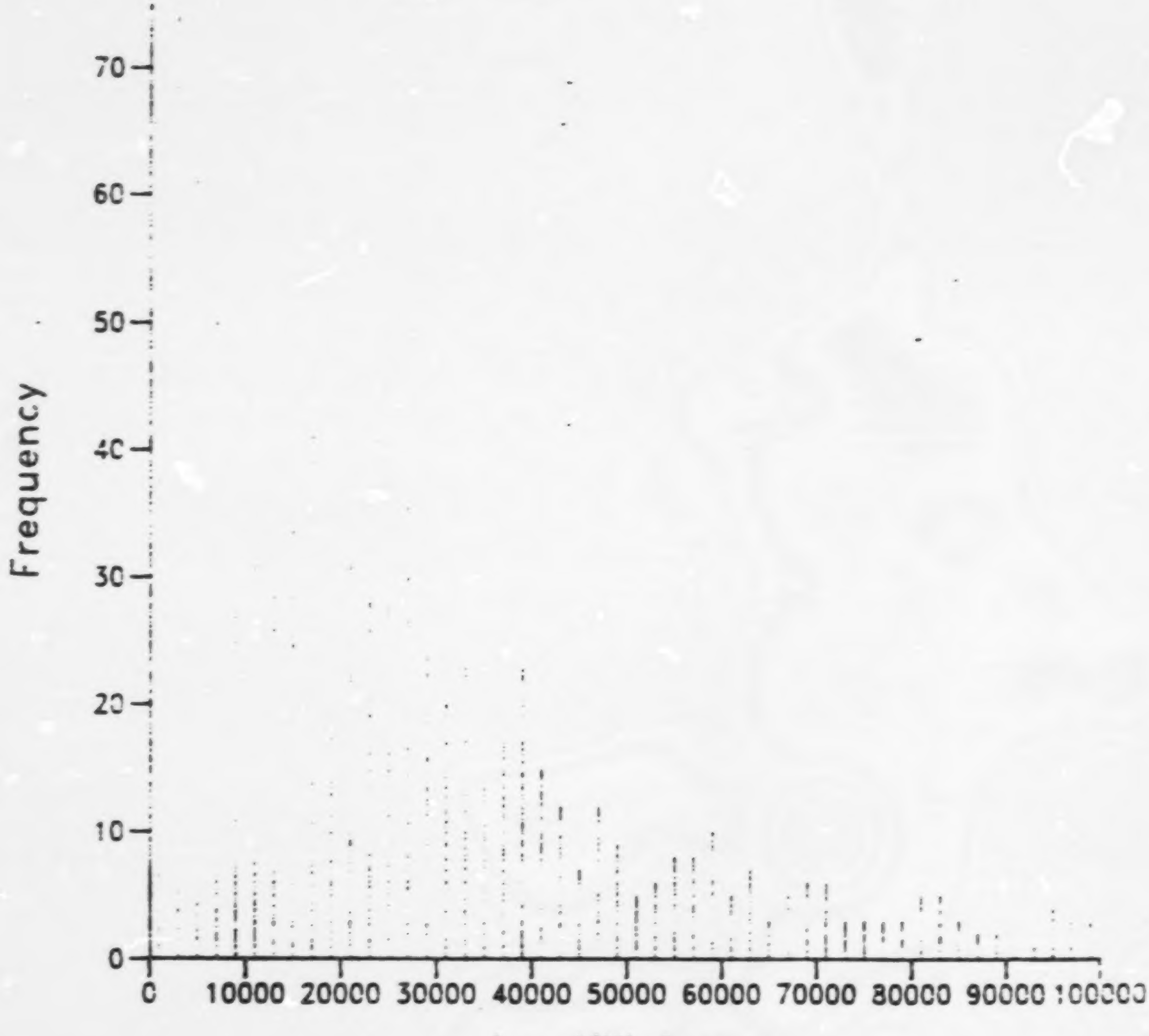
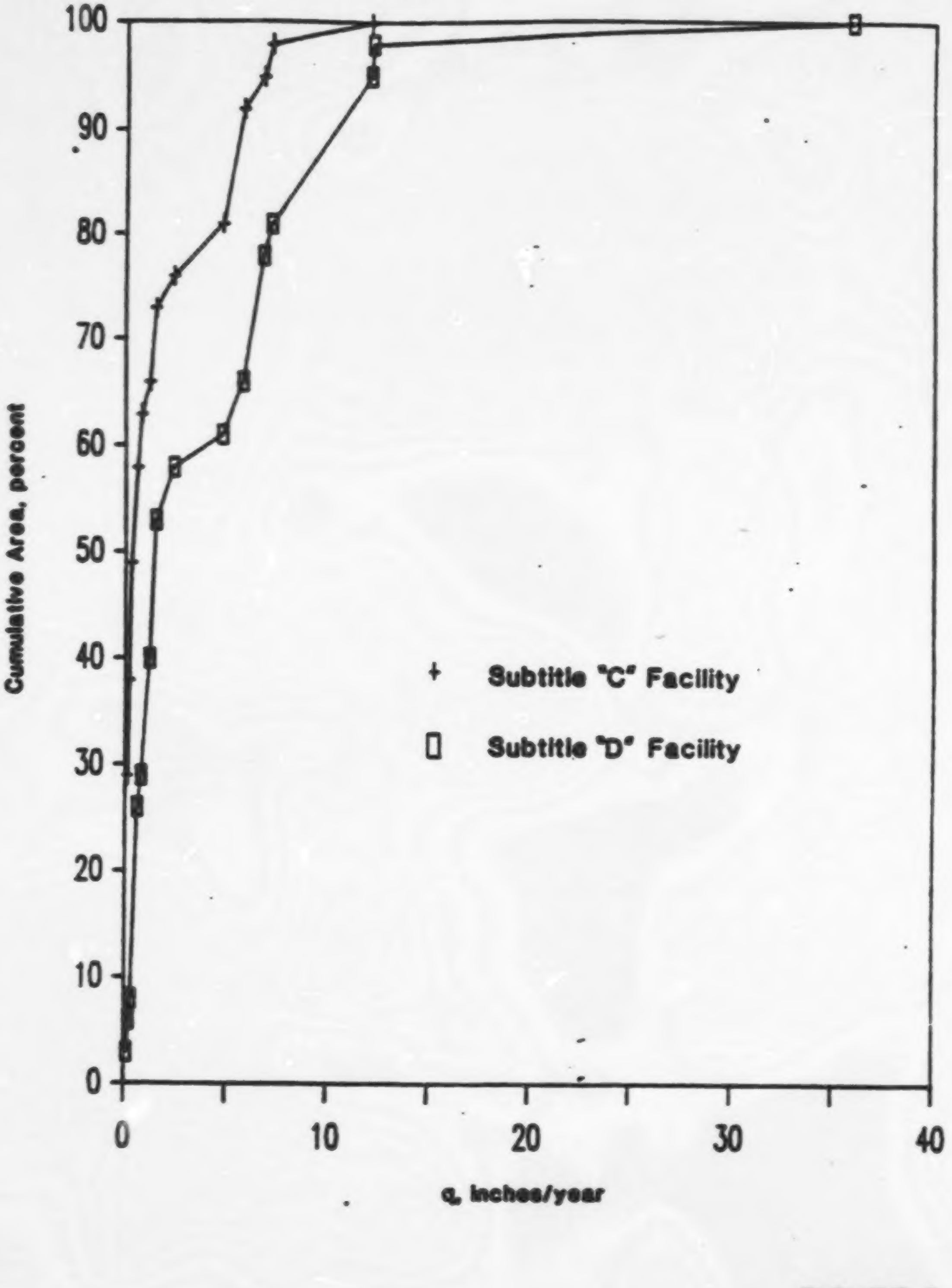

Frequency
70
60
50
40
30
20
10
0
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
Landfill Areas

FIGURE 8



9

FIGURE 3-1
ESTIMATED DISTRIBUTION OF UNIT AREA LEACHING RATES FOR SUBTITLE C AND D FACILITIES

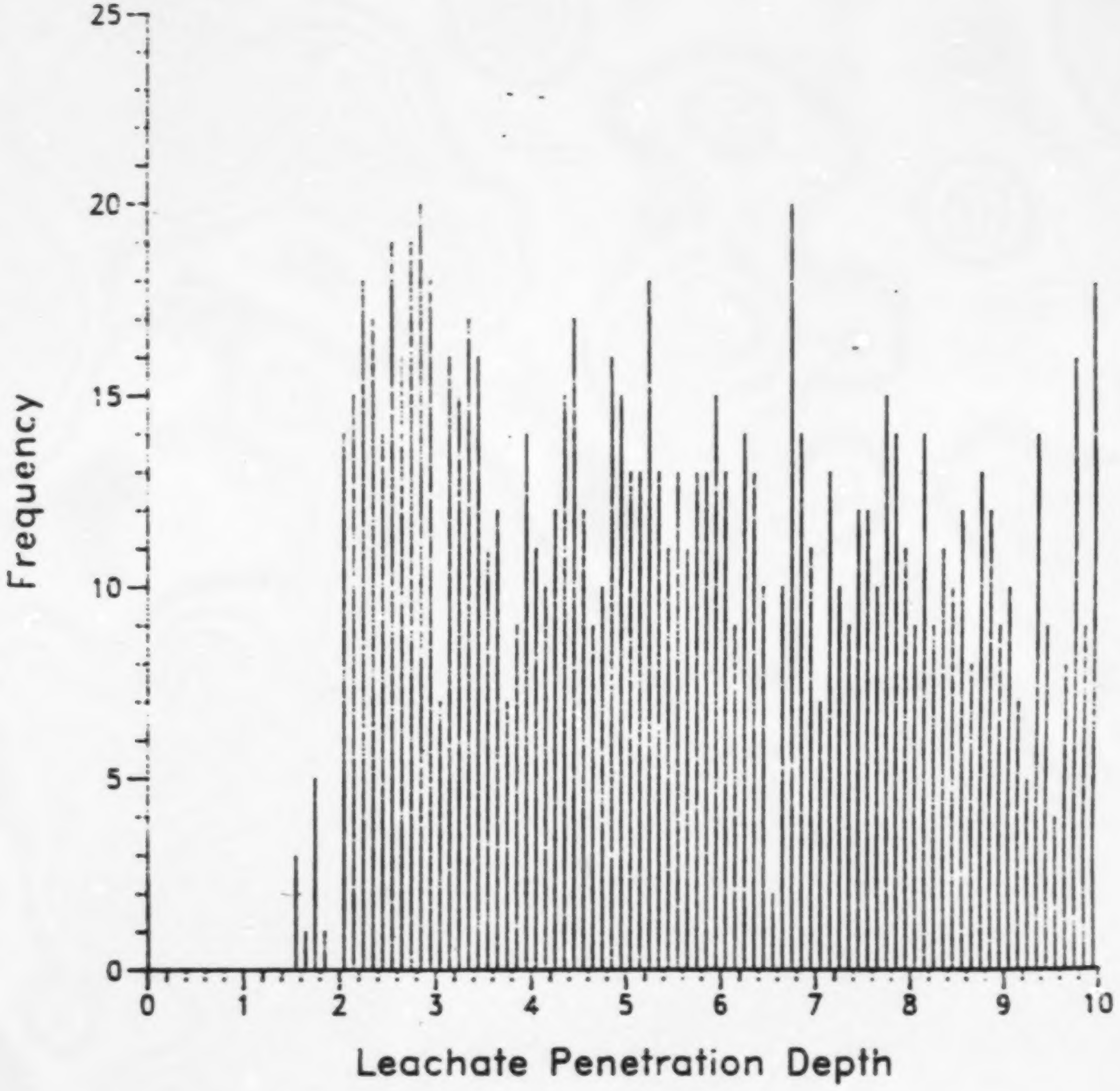

Frequency
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
10
Leachate Penetration Depth

FIGURE 10

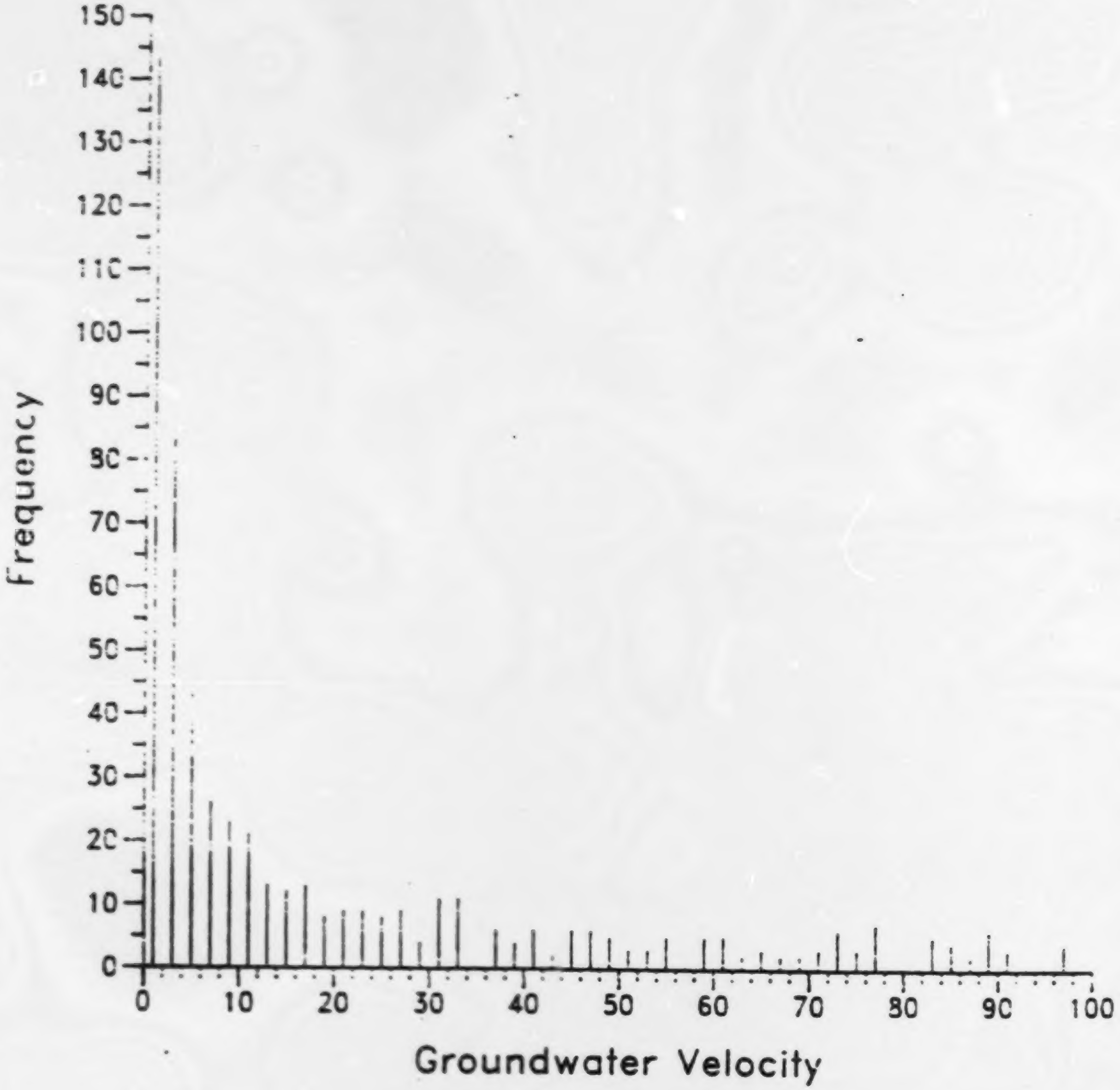

Frequency
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Groundwater Velocity

FIGURE 11

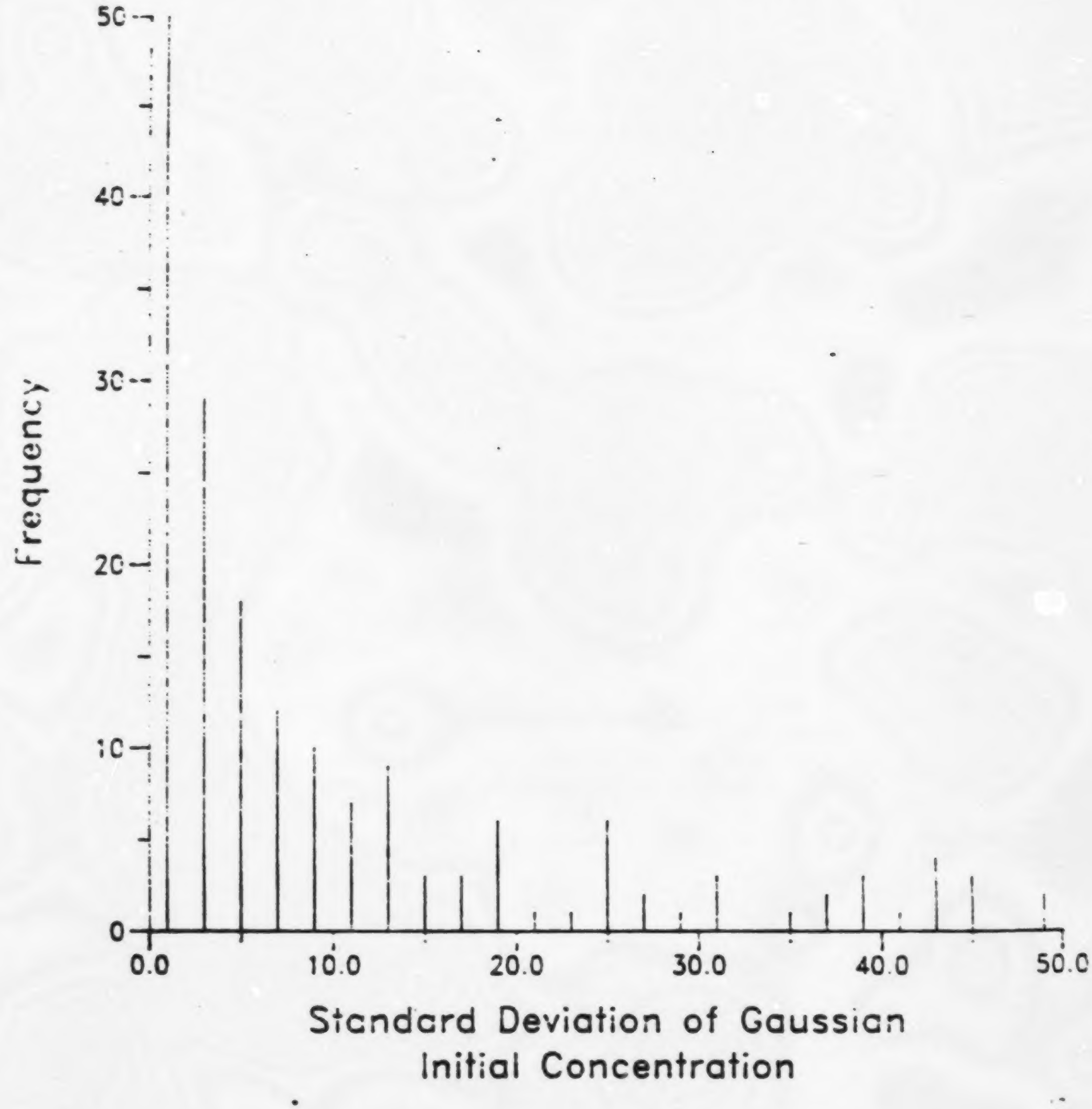

50
40
30
20
10
0
Frequency
0.0
10.0
20.0
30.0
40.0
50.0
Standard Deviation of Gaussian
Initial Concentration

FIGURE 12

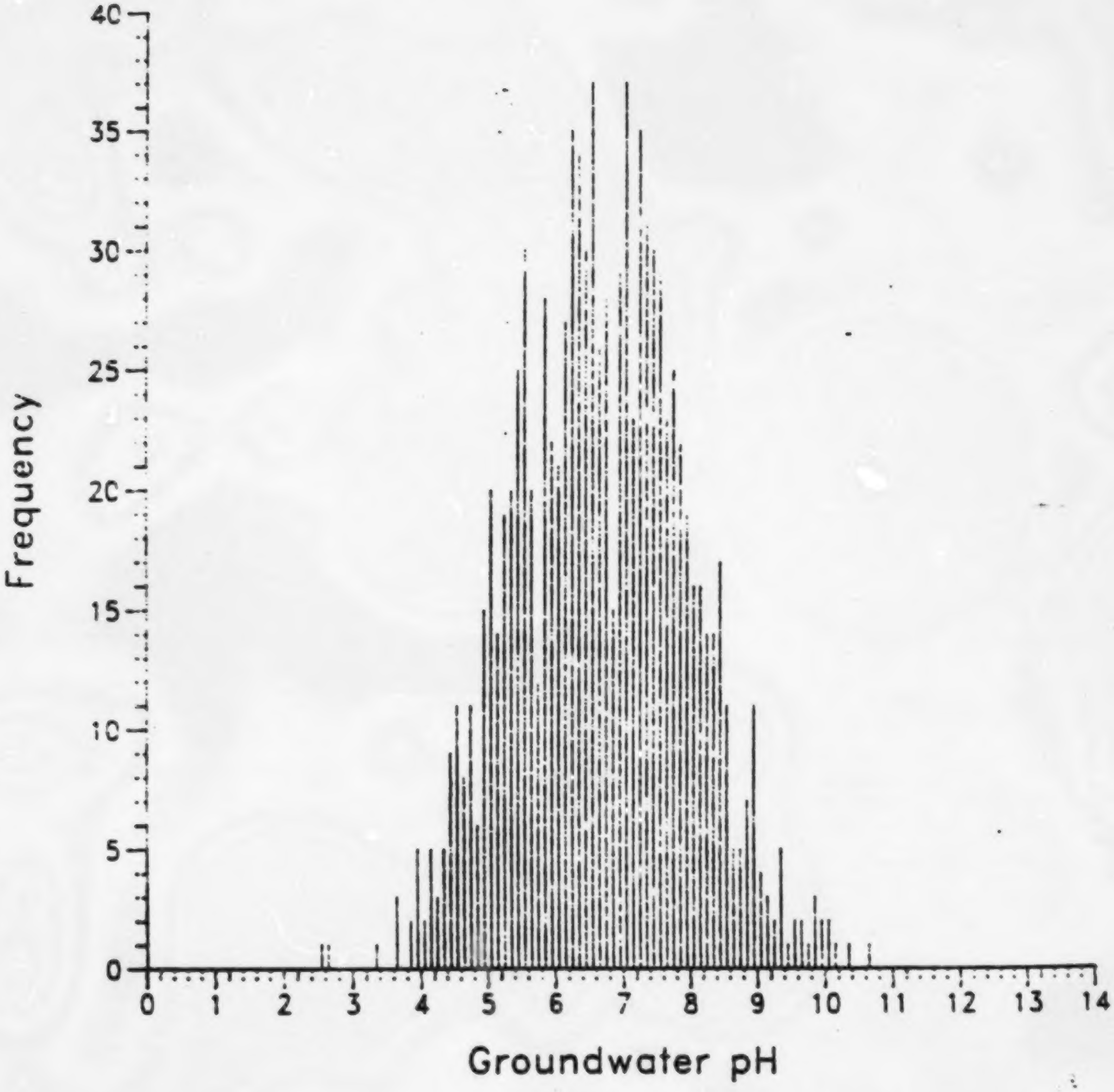

Frequency
0
5
10
15
20
25
30
35
40
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Groundwater pH

FIGURE 13

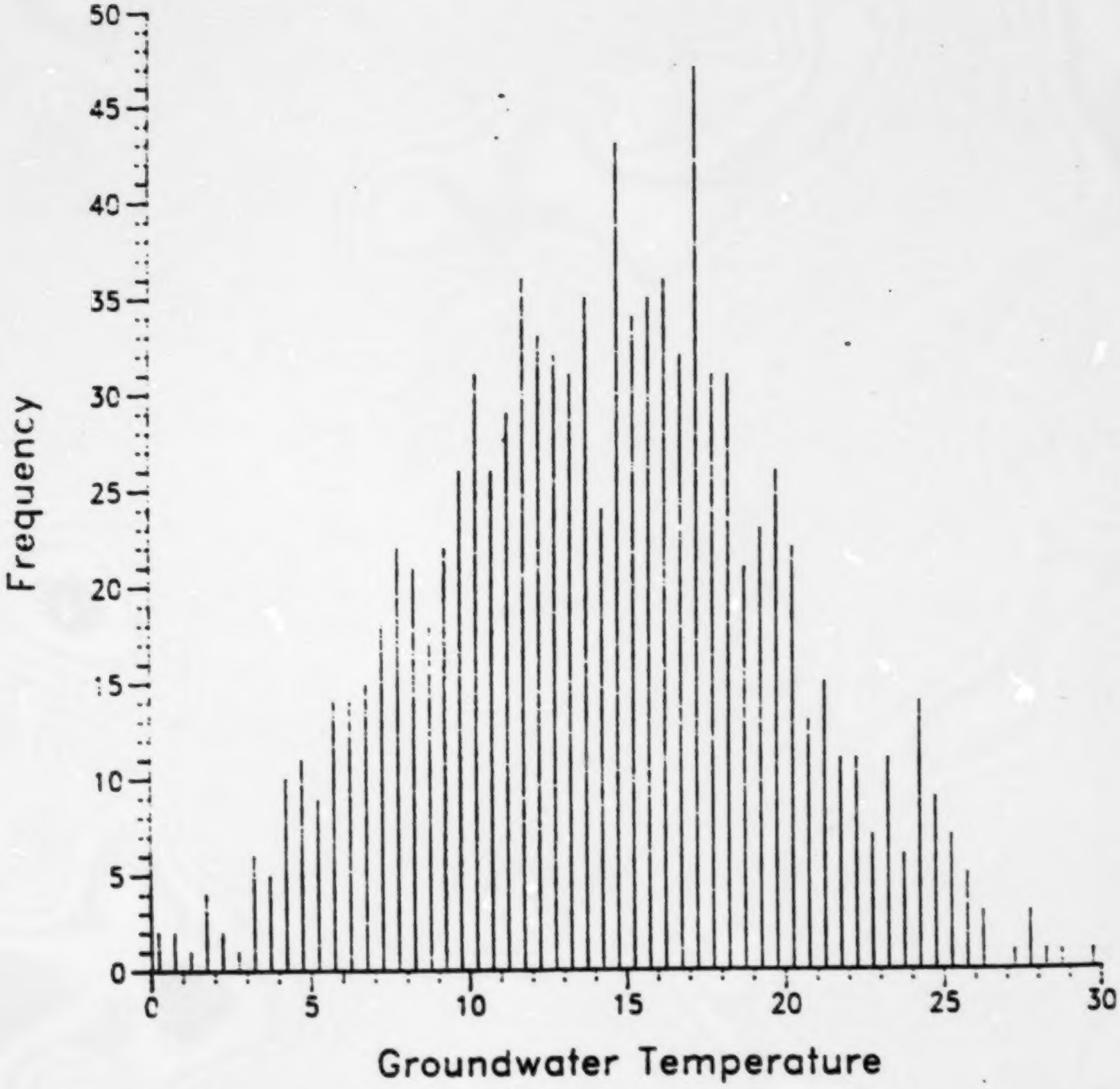

Frequency
50
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Groundwater Temperature

FIGURE 14

5.0 Modeling Results

The groundwater model was implemented with the input data generated by the data, assumptions, or modeling reported in the previous sections. Two general cases are of interest: modeling results for non-degrading chemicals, and for degrading chemicals.

5.1 Results for Nondegrading Chemicals

The behavior of all non-degrading organic chemicals will be identical because sorption does not (as implemented in the model) influence dissolved concentrations. Thus, it is possible to produce a single cumulative frequency distribution for all such compounds. The resulting distribution is given in Figure 15. In addition to the graphical results, tabulated values for the frequency distribution are given in Table 4. Also given in the table are results from simulations using a neutral hydrolysis rate corresponding to a one-year half-life with no sorption.

Table 4. Model Simulation Results for Non-Degrading Chemicals and Chemicals with a One Year Halflife

Cumulative Percentile	*CD Value Non-Degrading Case	One Year Halflife
0.25	$<0.0 \times 10^{-7}$	1.0×10^{-6}
0.50	1.8×10^{-5}	2.0×10^{-5}
0.75	0.0044	0.0046
0.90	0.043	0.043
0.95	0.09	0.10

*CD = C_{ADI}/C_L

where C_{ADI} = health-based threshold

C_L = leachate concentration

365 DAYS (12 MONTHS)

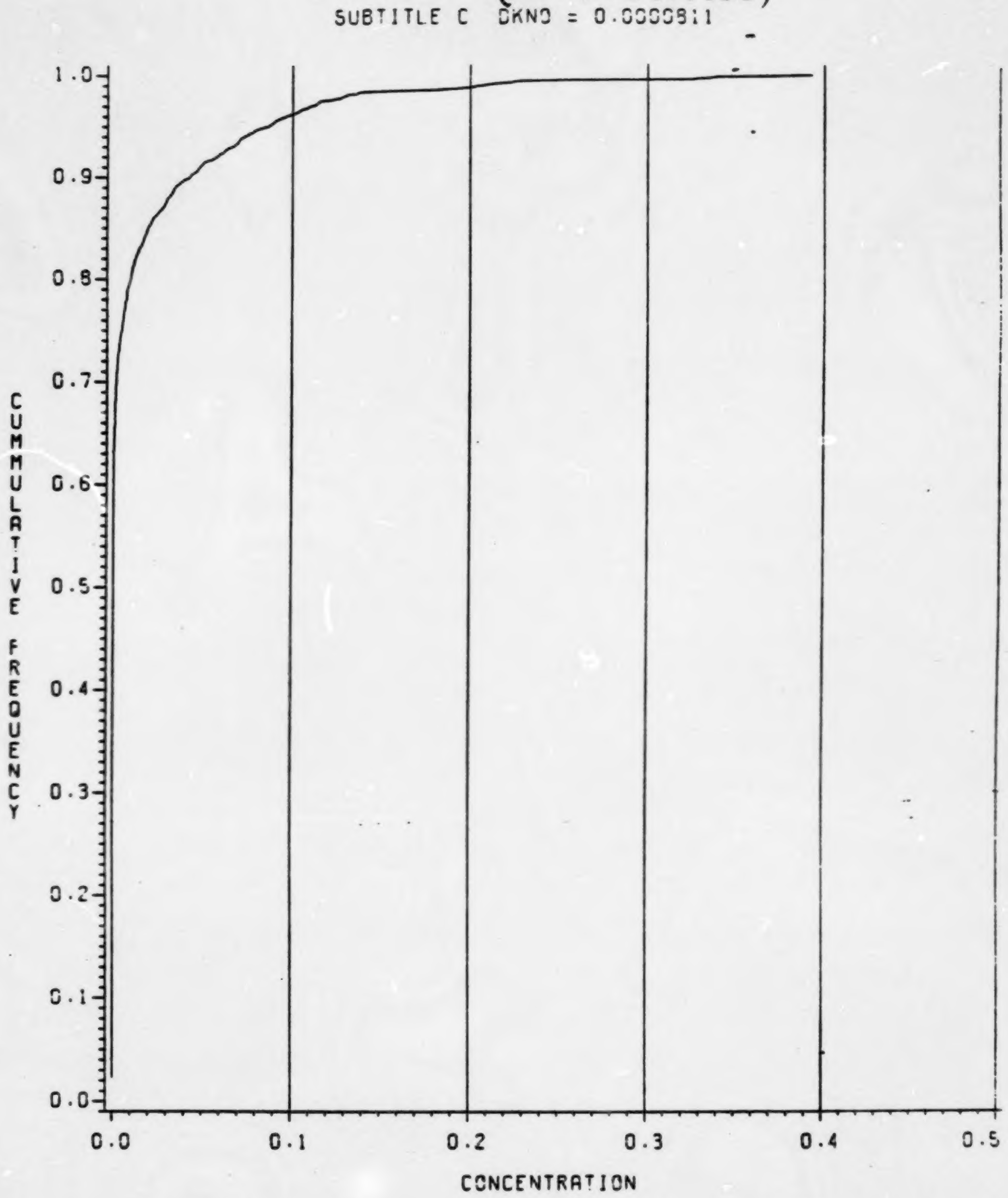


FIGURE 15

5.2 Results for Degrading Chemicals

All degrading chemicals will respond to differences in both rate constants (k_a, k_n, k_b) and partition coefficients (K_D). For this reason no general result can be developed, rather, a unique cumulative frequency curve exists for each individual chemical. To illustrate general differences between behavior of chemicals that do not degrade and those that degrade a series of simulations shown in Figures 16 - 21 were produced representing chemicals that do not sorb but have varying effective half-lives. These results compared to those of Figure 13 illustrate the dramatic impact that degradation can have at "fast" rates but also show a surprisingly small effect at "slow" rates. Table 5 summarizes the results for different rate constants.

Table 5. Model Simulation Results for Degrading Chemicals That Do Not Sorb

Cumulative Percentile	CD Value for Each Noted Halflife					
	30 days	60 days	90 days	8 months	16 months	2 years
0.25	$8.0x10^{-6}$	$9.0x10^{-6}$	$9.2x10^{-6}$	$9.7x10^{-6}$	$1.0x10^{-5}$	$1.0x10^{-5}$
0.50	$1.7x10^{-5}$	$1.8x10^{-5}$	$1.8x10^{-5}$	$1.8x10^{-5}$	$1.8x10^{-5}$	$1.84x10^{-5}$
0.75	$3.6x10^{-3}$	$4.0X10^{-3}$	$4.4x10^{-3}$	$4.5x10^{-3}$	$4.5x10^{-3}$	$4.5x10^{-3}$
0.90	$3.5X10^{-2}$	$3.8x10^{-2}$	$3.9x10^{-2}$	$4.2x10^{-2}$	$4.3x10^{-2}$	$4.3x10^{-2}$
0.95	$7.5X10^{-2}$	$8.2x10^{-2}$	$8.5x10^{-2}$	$8.6x10^{-2}$	$8.7x10^{-2}$	$8.8x10^{-2}$

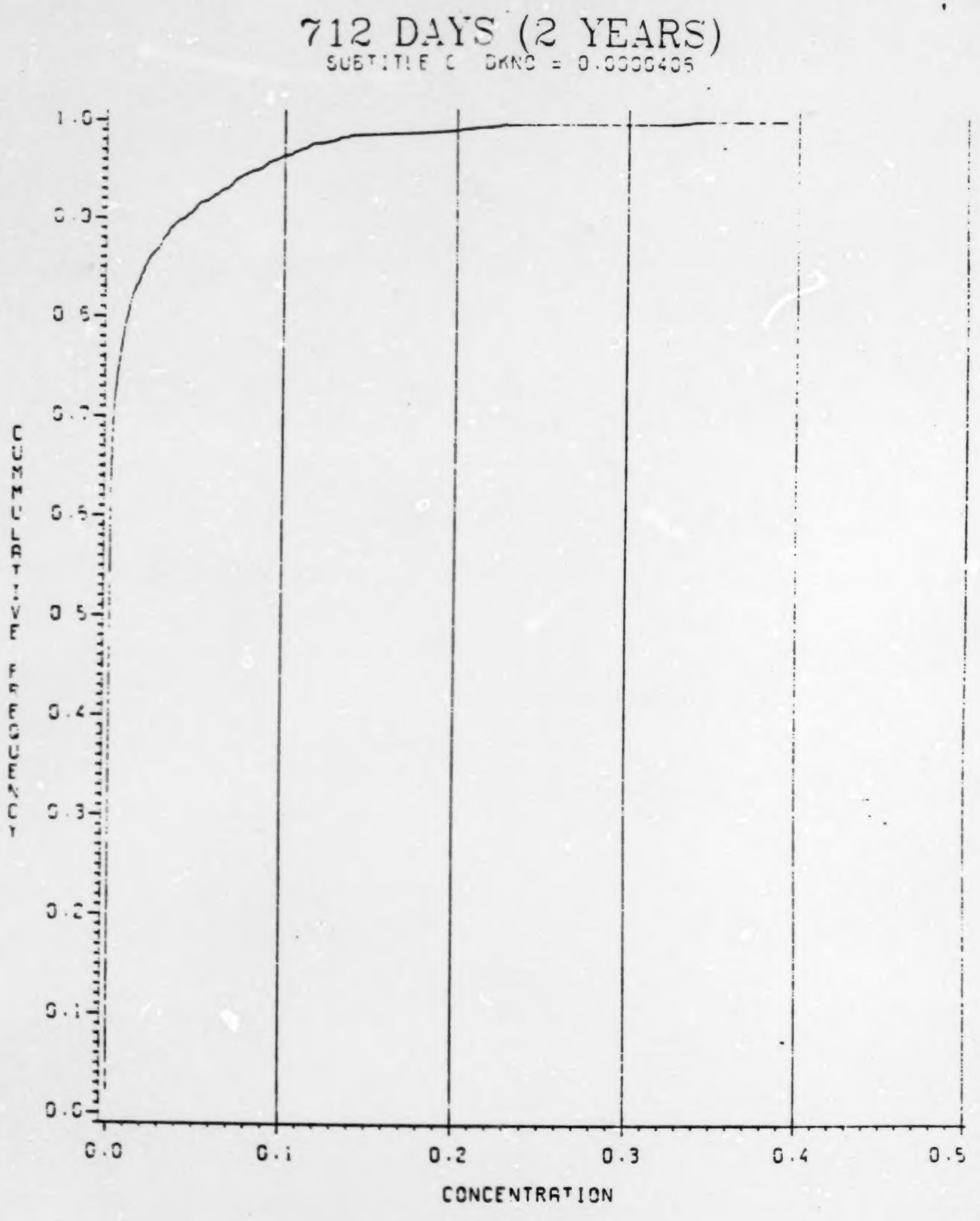

712 DAYS (2 YEARS)
SUBTITLE C DKNC = 0.0000405
CUMULATIVE FREQUENCY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
0.1
0.2
0.3
0.4
0.5
CONCENTRATION

FIGURE 16

480 DAYS (16 MONTHS)

SUBTITLE C DKNO = 0.0000602

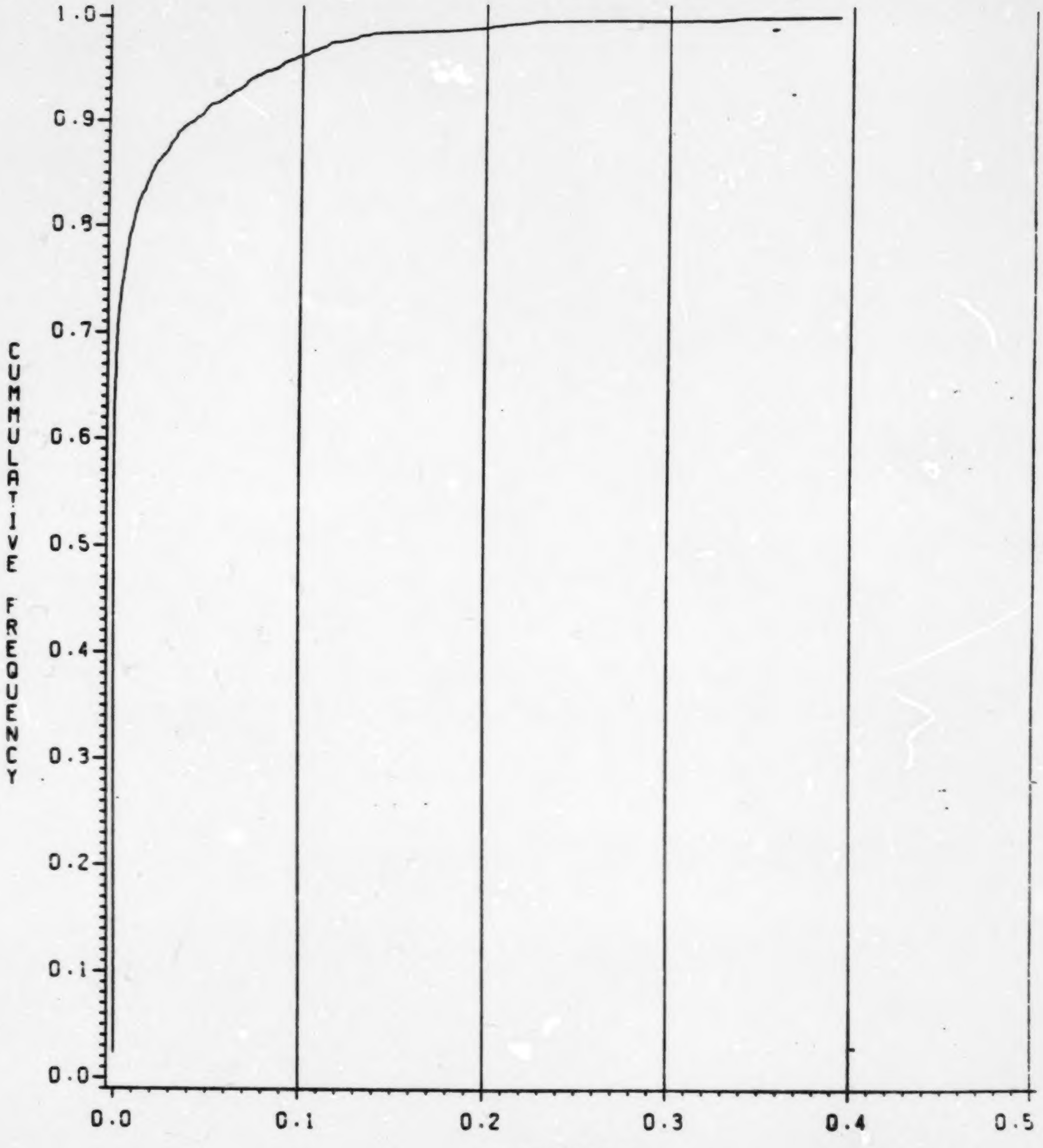


FIGURE 17

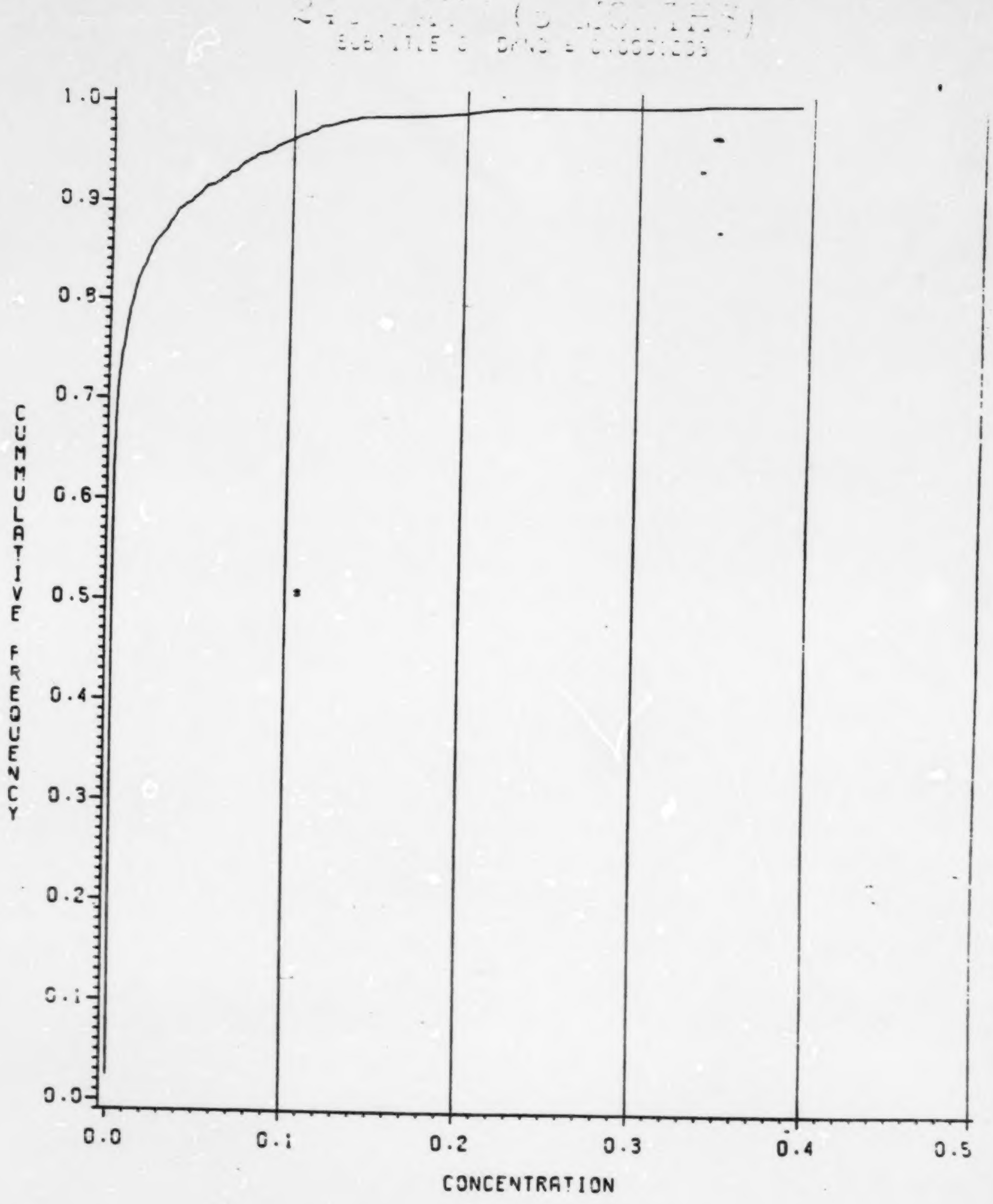


FIGURE 18

Reproduced from best available copy.

90 DAYS

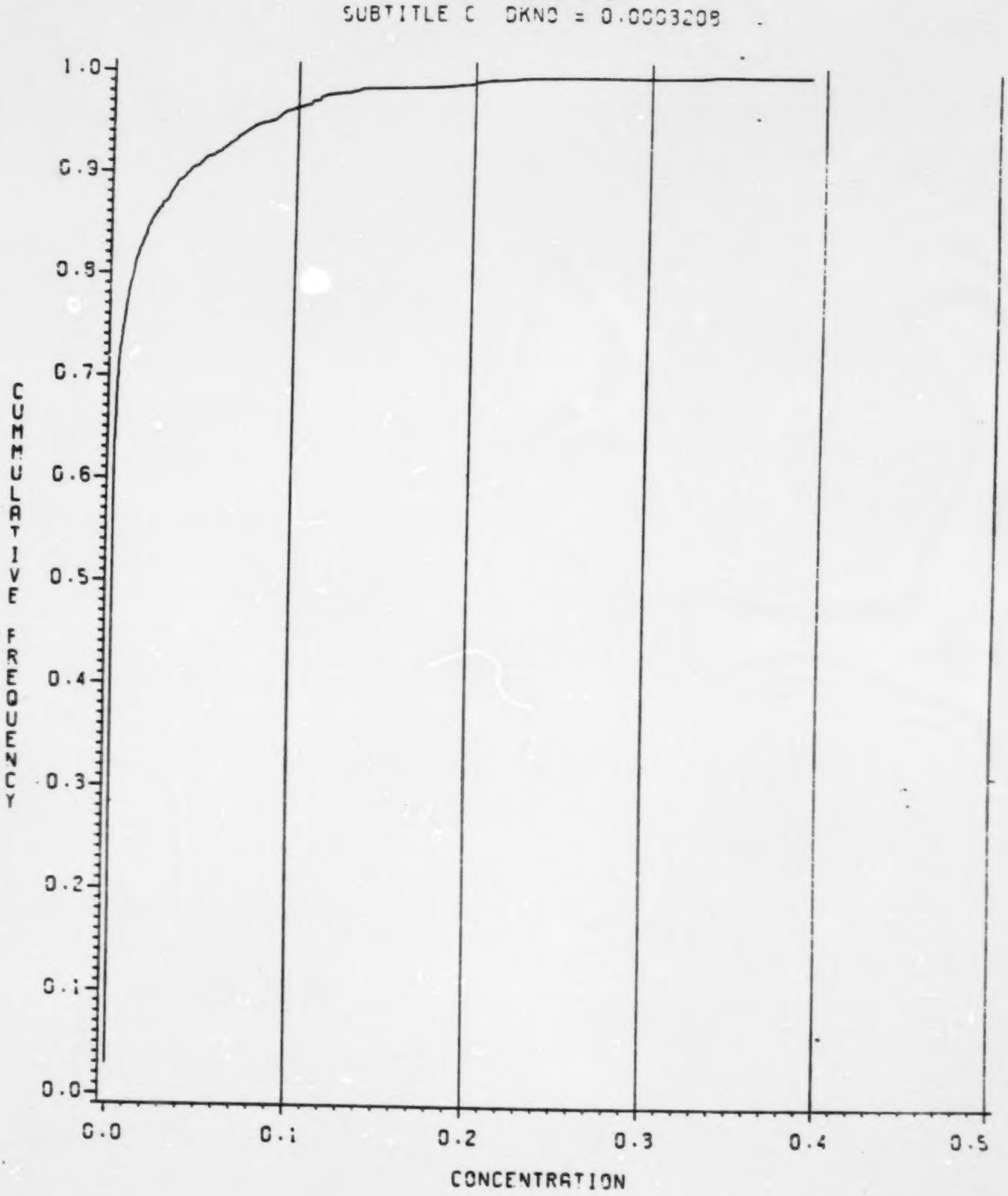
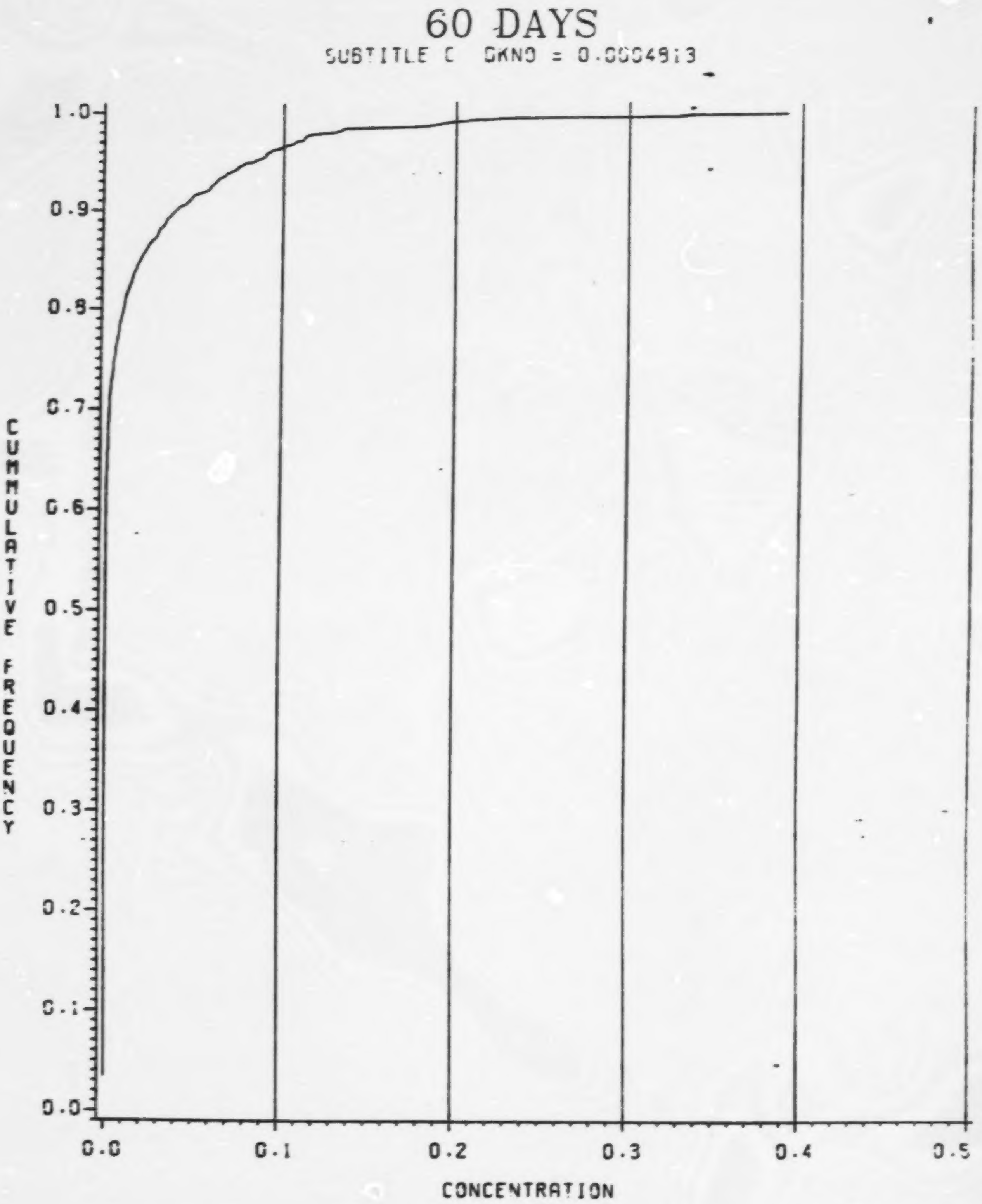


FIGURE 19


60 DAYS
SUBTITLE C DKNO = 0.0004813
CUMMULATIVE FREQUENCY
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0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.0
0.1
0.2
0.3
0.4
0.5
CONCENTRATION

FIGURE 20

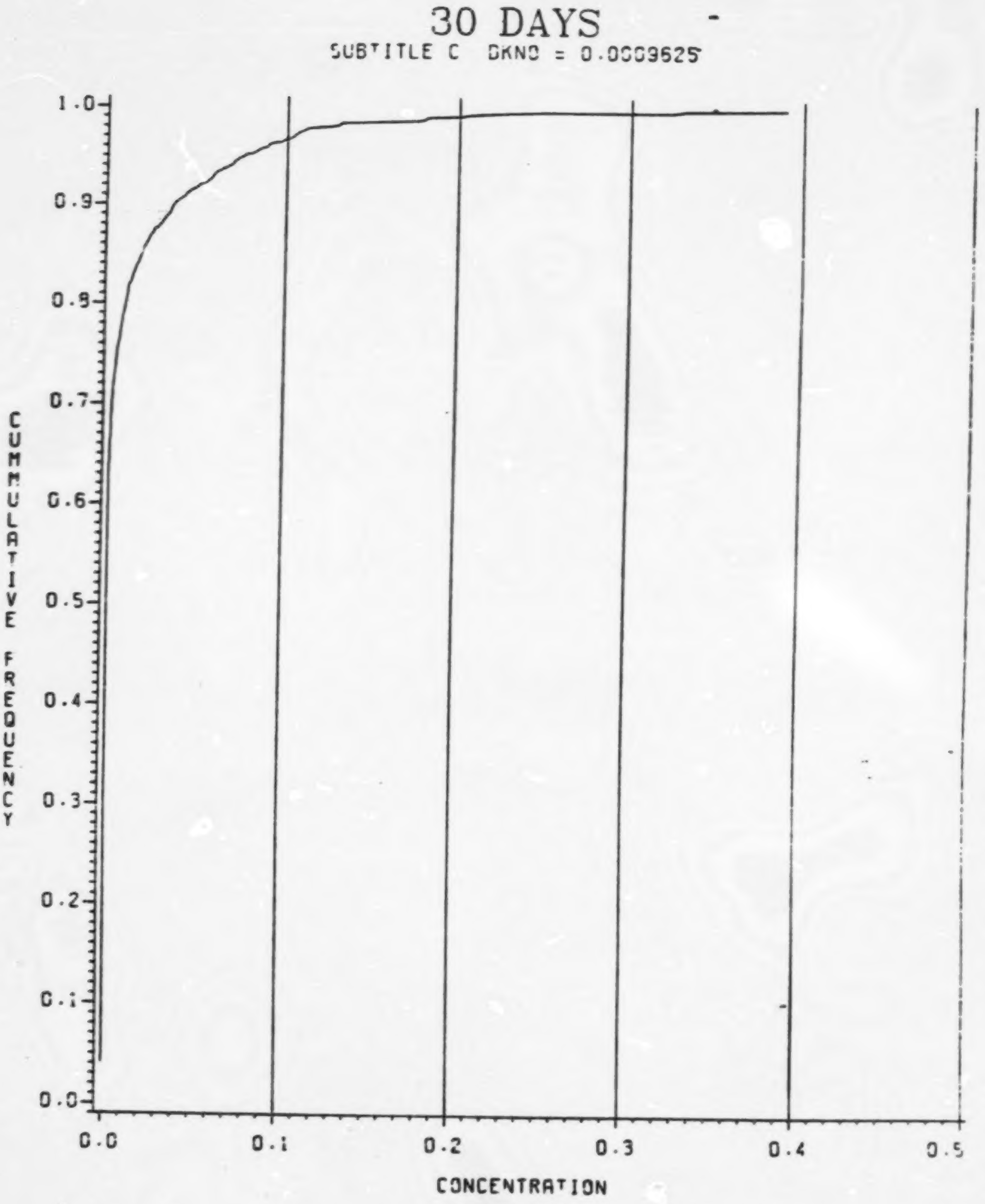
30 DAYS
SUBTITLE C DKNO = 0.0009625
CUMMULATIVE FREQUENCY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
0.1
0.2
0.3
0.4
0.5
CONCENTRATION

FIGURE 21

6.0 Limitations in the Approach and Issues

The results obtained from the monte carlo simulations are intended to represent the performance of land disposal systems as they *can* exist over the entire country. Attempts have been made as presented in this report to accurately represent the range of possible outcomes of this process. Given the required assumptions, however (including in some cases assumptions of independence when weak dependence is known to exist), it is recommended that *extreme* values of the derived distributions be viewed as suspect. For this reason, values in excess of the 95th percentile level and below the 5th percentile level should not be viewed as having the "accuracy" of those values intermediate to these extremes.

Recall from the statement of objectives the intent to include an explicit representation of the measurement errors associted with hydrolysis and sorption experiments. This has not yet been done but is under development. For chemicals that do not degrade this is not a requirement. Limited sensitivity analysis to date for degrading compounds suggests that for certain ranges of halflives the outcomes are relatively insensitive, especially near distribution extremes.

Increased confidence in the modeling results can be achieved by completing the following activities:

(1) developing better distributions for subsurface properties, particularly mean particle sizes and related phenomena based on a more comprehensive review of subsurface data

(2) expanding the spatial and temporal extent of the HELP model simulations (as described in the E. C. Jordan report, 1985) for leachate volumes

(3) developing a correlated distribution generation approach for the leachate penetration depths, H, q, and V

(4) relating dispersitivities to porous medium properties (probably hydraulic conductivities) as well as scale

(5) developing analytic expressions for the sensitivity functions of the model

(6) conducting exhaustive sensitivity analyses to determine exact sources of the major model sensitivity

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3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 Leaching Rate Distributions

Leaching rates for Subtitle C (hazardous) and Subtitle D landfill facilities were estimated with the HELP model for conditions considered representative of long-term performance. Leaching rates were estimated for 18 climatic conditions encountered in the contiguous 48 states. A summary of leaching rates is provided in Table 3-1. This information is expressed as percent of area in the contiguous 48 states where leaching rates may be expected to equal or be less than the rate shown.

Estimates of leaching rates suggest the rates are not randomly distributed in the contiguous 48 states, but are highly dependent on the annual precipitation. Leachate was estimated for all chosen locations of Subtitle D facilities. These leaching rates ranged approximately 2 orders-of-magnitude (100 fold) from Pocatello, ID to Astoria, OR (35.9 inches per year), while precipitation ranged over one order-of-magnitude. Long-term leaching was not estimated to occur at Subtitle C facilities receiving less than 20 inches per year of precipitation (with one exception). Where leaching was estimated to occur at Subtitle C facilities, the rate was generally 2 to 3 times less than for Subtitle D facilities.

The distributions of leaching rates shown in Figure 3-1 indicate Subtitle C facilities are expected to leach at a rate less than for Subtitle D facilities.

TABLE 3-1

LEACHING RATES SUMMARY[a]

PRECIPITATION RANGE[b]	EVAPORATION POTENTIAL	LEACHING RATE[b]		CLIMATOLOGICAL CENTER	AVERAGE 5-YEAR PRECIPITATION[b]	PERCENT OF TOTAL AREA[c]
		"C"	"D"			
<10	Low	0.0	0.1	Pocatello, ID	9.8	3
	Medium	0.0	0.3	Cedar City, UT	9.8	2
	High	0.0	0.2	Las Vegas, NV	5.3	3
10-20	Low	0.0	0.8	Great Falls, MT	17.9	3
	Medium	0.0	0.6	Rapid City, SD	15.4	18
	High	0.4	1.2	Midland, TX	16.3	11
20-32	Low	0.3	1.5	St. Cloud, MN	25.8	9
	Medium	0.5	1.5	Grand Island, NE	22.2	4
	High	0.5	2.4	Oklahoma City, OK	30.4	5
32-40	Low	3.6	7.2	Montpelier, VT	34.5	3
	Medium	3.7	6.8	Cleveland, OH	36.7	5
	High	2.9	4.8	Columbia, MS	37.1	3
40-48	Low	7.0	12.1	Boston, MA	40.9	3
	Medium	3.3	6.8	Indianapolis, IN	40.3	7
	High	2.5	5.8	Charleston, SC	48.3	5
>48	Low	11.9	35.9	Astoria, OR	65.6	2
	Medium	7.1	12.2	Knoxville, TN	48.1	3
	High	6.9	12.1	Tallahassee, FL	68.4	11

---

[a] Based on USEPA HELP model estimates. Estimates for Subtitle C facilities assume an evapotranspiration zone of 36 inches and 24 inches for Subtitle D facilities.

[b] Inches per year (assumes unit area).

[c] Percent of total area of contiguous 48 states.

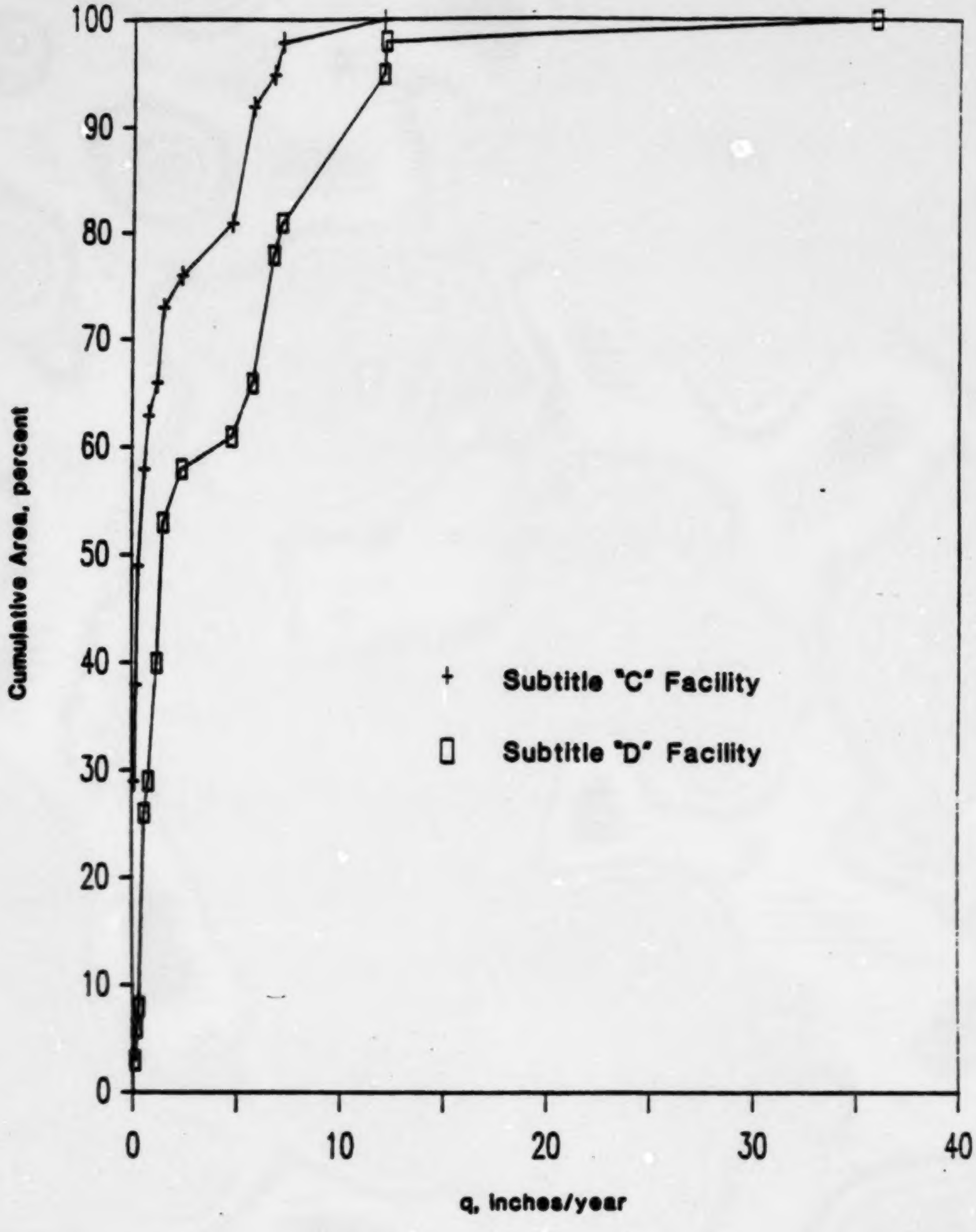

FIGURE 3-1
ESTIMATED DISTRIBUTION OF UNIT AREA LEACHING RATES FOR SUBTITLE C AND D FACILITIES

E.C.JORDAN CO.

The distributions may be better defined if more climatological centers are evaluated (up to 100 reporting cities are included in the HELP data base), but the basic trends and differences are not expected to change dramatically.

3.2 Sensitivity Analysis

Since the leaching rates shown in Table 3-1 and Figure 3-1 were estimated for a standard set of conditions, an analysis was conducted to determine the effect on leaching rate over a range of conditions that may be encountered. This analysis was conducted using Indianapolis, IN. Other climatological centers would be expected to respond in a similar manner. Conditions that were varied included cover soil texture, hydraulic conductivity of the barrier layer and evapotranspiration zone.

Cover soil texture effect on estimated leaching rates was analyzed for loamy sand and clayey loam. These soils are considered reasonable substitutes for the loam soil that was used in the standard conditions. As may be expected, use of more permeable loamy sand in the cover to support vegetation was found to yield more leachate than loam. The leaching rate was almost doubled for the Subtitle C facilities while it was tripled for Subtitle D facilities. The leaching rate was less affected by use of clayey loam instead of loam (<10 percent at Subtitle C facilities and <20 percent at Subtitle D facilities). This suggests that the use of cover soils less permeable than loam will have a minor effect on the estimated leaching rate whereas the use of more permeable cover soils will increase leaching rates more at Subtitle D facilities than at Subtitle C facilities.

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TABLE 3-2

SENSITIVITY ANALYSIS SUMMARY

CONDITION	LEACHING RATE[a] q_C	LEACHING RATE[a] q_D
Standard Conditions[b]	3.3	6.8
Soil Texture		
Loamy Sand	6.11	19.71
Clayey Loam	2.97	5.22
Hydraulic Conductivity, k		
5×10^{-6} cm/sec	4.3	-
5×10^{-7} cm/sec	2.2	-
Evapotranspiration (E-T) Zone		
Depth = half of standard condition	7.34	11.6

[a] inches per year (assumes unit area) for Indianapolis, IN location: q_C = Subtitle C facility
q_D = Subtitle D facility

[b] Standard Conditions included:

cover soil texture	loam
barrier layer hydraulic conductivity	10^{-6} cm/sec
evapotranspiration zone	36 inches for Subtitle C facility 24 inches for Subtitle D facility

3 Hydraulic conductivity in barrier layers in cover or liner systems was varied from $5x10^{-6}$ to $5x10^{-7}$ cm/sec to determine the effect on leaching rate from the standard condition of 10^{-6} cm/sec. Since Subtitle D facility cover systems were not assumed to provide such a barrier layer, the analysis was limited to Subtitle C facilities. The analysis indicated changes in leaching rates on the order of approximately 50 percent.

Reducing the depth of the zone where evapotranspiration may occur increased the Subtitle C leaching rate by a factor of almost 2.5, while the Subtitle D leaching rate increased by a factor of 1.7. This difference in effect on leaching rates caused by reducing the evapotranspiration zone suggests that the greater depth used for the Subtitle C facility (36 inches) provides more control over leaching rates than the shallower depth (24 inches) used for Subtitle D facilities.

Comparison of the relative importance of the conditions analyzed indicated the evapotranspiration depth is the most important condition for estimating Subtitle C leaching rates followed by use of more permeable soils for barriers and cover systems. The same two conditions, but in reverse order, were the most important in affecting Subtitle D leaching rates. In all cases, Subtitle D leaching rates were greater than for Subtitle C.

The sensitivity analysis was conducted over a reasonable range of long-term conditions. The estimated leaching rates over these ranges therefore provide a means of estimating the range of leaching rates that may be expected for these facilities under climatic conditions represented by Indianapolis, IN. Subtitle C facilities in Indianapolis may leach at a rate ranging from 2.2 to 7.34 inches per year, whereas, a Subtitle D leaching rate may range from 5.22 to 19.71 inches per year. The range of leaching rates may be greater if more than one standard condition is varied.

3.3 Application of Distributions

3.3.1 Use. Leaching rates and their frequency of occurrence in the contiguous 48 states were estimated for use in developing a generic procedure to classify wastes as hazardous and determine hazardous wastes to be banned from Subtitle C land disposal facilities. The leaching rates provide a means of estimating the chemical flux (mass rate of chemical release) from both Subtitle C and D facilities. The volumetric flux (volumetric rate of leachate production) identifies the transport rate which is leaching mobile chemicals out of the facility. When leaching rate is multiplied by concentration of chemicals in the leachate, then the chemical flux is described on a unit area basis. It is appropriate to express this flux on a unit area to maintain the generic application of the procedure.

The generic procedure is to be used to select chemical concentration criteria for use with a simple extraction procedure (e.g., Extraction Procedure III - organics). The EPA must ultimately select a specific leaching rate to determine the chemical concentration criterion that is protective of human health and the environment. Maximum protection is provided by selecting the greatest leaching rate.

Selection of an appropriate chemical concentration may be a complex task. An upper concentration limit may be identified as the solubility of the chemical in an aqueous solution. This assumes that wastes placed in the facility are not, or do not, contain free liquids and must dissolve into precipitation that percolates through the wastes. This approach to identifying a chemical concentration has several limitations:

- not all chemicals have solubility limits in water (i.e., some chemicals are miscible in water);
- solubility concentrations are rarely attained because of the inherent kinetics of the leaching process and chemical equilibria; and
- may far exceed actual leachate concentrations.

Alternatively, an appropriate concentration can be estimated by an iterative process to determine the concentration that, when released to an underlying groundwater system and transported downgradient to a receptor, does not cause adverse human health or environmental effects. This iterative process can be conducted after a specific leaching rate is selected or can be conducted on a mass flux basis (e.g., product of leaching rate and chemical concentration). The appropriate leaching rate and concentration that meets the chemical flux criterion can then be selected.

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3.3.2 Limitations

Limitations of the leaching rate distributions and their use may be described as:

- analytical assumptions; and
- geographical distribution of leaching rates.

The analytical approach has several limitations that were described in Section 2. These limitations relate to the data base used to project long-term performance. Use of the HELP model is based on 5 consecutive years of climatic data. Although an assessment was made that suggested limited differences in average precipitation for the 5-year and 25-year periods, the significance of several years of abnormally high precipitation or permanent shift in climatic conditions has not been evaluated.

The conditions projected to prevail in the long-term are not based on an extensive long-term data base. Reasonable assumptions were made to identify a range of conditions that may prevail in the future. A particularly important assumption was that performance is controlled by natural activities and not by human disturbance of the low permeable barrier.

Geographical distribution of the estimated leaching rates presents a limitation to its use in the generic procedure. Low leaching rates prevail in certain areas of the nation and high leaching rates in other areas. If a leaching rate is selected in establishing criteria for specific chemicals, then two undesirable effects may occur:

- over-regulation of wastes in areas with low leaching rates; and
- under-regulation of wastes if the leaching rate is larger than the rate selected for the criterion.

Under-regulation of wastes can be avoided by using the maximum estimated leaching rate for selecting chemical concentration criteria. Both limitations can be avoided by establishing land disposal banning criteria expressed as a mass flux (e.g., the product of leaching rate and concentration). The owner/operator of a specific facility could readily identify if a waste with appropriate testing results (i.e., EP-III) is banned. This approach allows higher concentrations in areas with low leaching rates and requires low concentrations in areas with high rates. Using the mass flux rate approach, the rule or classification procedure becomes national in scope, avoids over- or under-regulation, protects human and the environment, and allows climatic conditions and costs to control where wastes are deposited in a protective manner.

3.3.3 Summary

The analysis of engineered controls for land disposal of wastes yielded distributions of leaching rates (Figure 3-1) for the contiguous 48 states. The Subtitle C distribution yielded estimated leaching rates that were always less (generally 1/2 to 1/3) than the Subtitle D leaching rates. The depth of the evaporative zone was found to be the most sensitive long-term site condition used to estimate leaching rates at Subtitle C facilities. Soil texture was found to be the most sensitive long-term site condition for Subtitle D facilities.

The distributions are useful in developing a generic procedure for classifying hazardous wastes and banning wastes from land disposal facilities. The EPA may use the distributions to develop chemical criteria in one of the following approaches:

- select a leaching rate and then determine an appropriate chemical concentration criterion; or
- determine an appropriate chemical mass flux rate from a facility by back-calculation from a health/environmental based criterion; and establish a mass flux criterion with regional maps of leaching rates for use by owners/operators of disposal facilities; or
- establish a concentration criterion using the maximum leaching rate and over-regulate wastes in low leaching rate areas; or
- establish a concentration criterion using a leaching rate that will under-regulate higher leaching rate areas and over-regulate lower leaching rate areas.

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APPENDIX A

COMPARISON OF 5 AND 30 YEAR PRECIPITATION DATA

APPENDIX A

COMPARISON OF 5-YEAR AND 30-YEAR PRECIPITATION DATA

Analysis of the long-term performance of engineered controls at waste disposal facilities relied on the 5-year precipitation data base used in the HELP model. The appropriateness of using a 5-year data base was assessed by comparing the 5 year average annual precipitation to an average from a longer period.

Average annual precipitation collected over a 23- to 30-year period for the climatological centers used in the analysis of engineering controls compiled from "Climates of the States" (NOAA, 1980). These data are presented in Table A-1 along with the 5-year annual average precipitation computed for the HELP model data base. Comparison of the two averages for each center showed differences in averages from less than 1 percent to 27 percent. The larger differences tend to occur in the low precipitation ranges. Two-thirds of the centers exhibited average annual precipitation differences of less than 5 percent. The 5-year HELP averages for those centers in the higher precipitation ranges (>32 inches per year) were generally greater than for the 30 year average. This general trend was reversed for the lower precipitation ranges. In addition, the larger differences (>5 percent) were generally because the HELP data base provided a larger average annual precipitation than the 30-year average.

Based on the above assessment of average annual precipitation, the following observations are made:

TABLE A-1

COMPARISON OF 5 AND 30 YEAR AVERAGE PRECIPITATION

PRECIPITATION[a] RANGE	EVAPORATION POTENTIAL	CLIMATOLOGICAL CENTER	AVERAGE PRECIPITATION[a]		PERCENT DIFFERENCE
			5-YEAR[b]	30-YEAR[c]	
<10	Low	Pocatello, ID	9.8	10.8	9
	Medium	Cedar City, UT	9.8	9.97[d]	1
	High	Las Vegas, NV	5.3	4.16	27
10-20	Low	Great Falls, MT	17.9	14.99	19
	Medium	Rapid City, SD	15.4	17.55	12
	High	Midland, TX	16.3	13.31	22
20-32	Low	St. Cloud, MN	25.8	26.84	3
	Medium	Grand Island, NE	22.2	23.41	5
	High	Oklahoma City, OK	30.4	31.73	4
32-40	Low	Montpelier, VT	34.5	33.23[e]	3
	Medium	Cleveland, OH	36.7	34.93	5
	High	Columbia, MS	37.1	37.39	0.7
40-48	Low	Boston, MA	40.9	41.50	1
	Medium	Indianapolis, IN	40.3	39.90	0.8
	High	Charleston, SC	48.3	48.73	0.8
>48	Low	Astoria, OR	65.6	66.34	1
	Medium	Knoxville, TN	48.1	46.18	4
	High	Tallahassee, FL	68.4	61.58	11

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a Inches per year (assumes unit area)
b Based on HELP model, May, 1985.
c Based on "Climates of the States".
d 24-year average.
e 23-year average.

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0056.0.0

- distribution of leaching rates estimated using the HELP model tend to over-estimate the long-term performance of land disposal facilities;

- the larger differences between the two precipitation averages are associated with the lower precipitation ranges (<20 inches per year) which were estimated to yield small leaching rates.

APPENDIX E

ANALYSIS OF ENGINEERED CONTROLS OF SUBTITLE C FACILITIES FOR LAND DISPOSAL RESTRICTIONS DETERMINATIONS

REVISED DISTRIBUTION OF LEACHING RATES

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REFERENCES

1.0 INTRODUCTION

As part of recent federal legislation, the U.S. Environmental Protection Agency (EPA) must review all listed hazardous wastes and determine which wastes should be banned from land disposal facilities. The general approach for identifying such wastes was developed by EPA's Office of Solid Waste (OSW). OSW's analytical procedure includes credits for engineering controls that are designed into Subtitle C facilities. These engineering controls are used to determine leaching rates from Subtitle C facilities based on long-term performance (e.g., beyond anticipated design life). An analysis of leaching rates from Subtitle C facilities and Subtitle D facilities was performed and reported in June and August of 1985 (Jordan, 1985). Jordan's analysis evaluated 18 climatic centers throughout the contiguous 48 states. Recommendations for future studies included 1) an increase in the number of cities evaluated; and 2) comparing leaching rates based on the 5-year HELP[1] model data base to a long-term (i.e., 20-years) precipitation data base. This report presents the results of the additional analyses conducted in accordance with those recommendations.

---

[1] Hydrologic Evaluation of Landfill Performance (Schroeder, et. al., 1984)

2.0 REVISED LEACHING RATE DISTRIBUTIONS

2.1 Analytical Approach

The analytical approach used for this evaluation is identical to that used in the June 1985 study in which a standard set of design and long-term conditions was used to estimate the leaching rates for Subtitle C and D facilities. In both studies these standard sets, along with climatological data, were entered into the HELP model resulting in a calculated leaching rate.

2.2 Climatic Data Base

In the June 1985 study a total of 18 climatic centers were identified for developing the national leaching rate distribution. As fifty percent of these locations yielded leaching rates of less than one inch for Subtitle C facilities, few data points were provided to establish the upper end of the leaching rate. To obtain more data for the higher leaching rates, 12 additional climatic centers with precipitation averages of greater than 20 inches were evaluated in the September 1985 study. The combined list of cities selected for evaluation is presented in Table 2-1. Included in the group are cities with an extended data base of up to 20 years that were also used for a sensitivity analysis (Section 3.0) of the leaching rate based on a comparison of the 5-year and 20-year climatic data.

TABLE 2-1

LEACHING RATES SUMMARY[a]

PRECIPITATION RANGE[b]	EVAPORATION POTENTIAL	LEACHING RATE[b] "C"	LEACHING RATE[b] "D"	CLIMATOLOGICAL CENTER	AVERAGE 5-YEAR PRECIPITATION[b] (20-YEAR)	PERCENT OF TOTAL AREA[c]
<10	Low	0.0	0.1	Pocatello, ID	9.8	3
	Medium	0.0	0.3	Cedar City, UT	9.8	2
	High	0.0	0.2	Las Vegas, NV	5.3	3
10-20	Low	0.0	0.8	Great Falls, MT	17.9	3
	Medium	0.0	0.6	Rapid City, SD	15.4	13
	Medium	0.02(0.04)	0.04	Denver, CO	13.0 (14.9)	5
	High	0.4	1.2	Midland, TX	16.3	11
20-32	Low	0.3	1.5	St. Cloud, MN	25.8	7.8
	Low	3.1 (3.4)	3.4	Milwaukee, WI	34.1 (33.1)[d]	2.2
	Medium	3.4	3.4	San Francisco, CA	(19.7)	2
	Medium	0.5	1.5	Grand Island, NE	22.2	2
	High	0.5	2.4	Oklahoma City, OK	30.4	5
32-40	Low	3.6	7.2	Montpelier, VT	34.5	3
	Medium	3.7	6.8	Cleveland, OH	36.7	2
	Medium	2.7	5.4	E.St.Louis, IL	36.2	3
	High	2.9	4.8	Columbia, MS	37.1	3
40-48	Low	7.0	12.1	Boston, MA	40.9	0.4
	Low	6.6	12.8	Providence, RI	46.7	0.1
	Low	4.6 (5.3)	10.0	Hartford, CT	41.1 (44.1)	0.2
	Low	5.5	14.2	Worcester, MA	46.5	1.6
	Low	5.7	13.0	Portland, ME	45.5	0.8
	Medium	(5.2)		Newark, NJ	(40.4)	0.3
	Medium	6.6	10.6	Philadelphia, PA	43.7	1.4
	Medium	3.3	6.8	Indianapolis, IN	40.3	5.2
	High	2.5	5.8	Charleston, SC	48.3	4.6
	High	6.4	11.4	Norfolk, VA	44.4	0.4
>48	Low	11.9	35.9	Astoria, OR	65.6	2
	Medium	7.1	12.2	Knoxville, TN	48.1	3
	High	6.9	12.1	Tallahassee, FL	68.4	5
	High	9.8(5.9)	16.7	New Orleans, LA	70.1(56.7)	5

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[a] Based on USEPA HELP model estimates. Estimates for Subtitle C facilities assume an evapotranspiration zone of 36 inches and 24 inches for Subtitle D facilities.

[b] Inches per year (assumes unit area); number in parenthesis indicates average based on 20 year database.

[c] Percent of total area of contiguous 48 states.

[d] 11 years of precipitation data.

2.3 Leaching Rate Distribution

In both studies leaching rates for Subtitle C and Subtitle D landfill facilities were estimated with the HELP model. Leaching rates were estimated in the September 1985 study for 30 climatic centers in the contiguous 48 states. A summary of the leaching rates is provided in Table 2-1. This information is expressed as percent of area in the contiguous 48 states where leaching rates may be expected to equal or be less than the rate shown.

The distributions of the leaching rates shown on Figure 2-1 do not indicate a significant change from the June 1985 distribution. The maximum leaching rates for Subtitle C and D facilities repeated the pattern of the initial study in that the Subtitle C leaching rates were generally 50 percent less than those for Subtitle D facilities. The distribution represents the estimated leaching rates based on the 5-year precipitation data base with the exception of New Orleans (Louisiana), San Francisco (California) and Newark (New Jersey) which were based on a more extensive data base. The 5-year precipitation data for New Orleans is substantially greater than the 20-year average (70.1 inches versus 56.7 inches); therefore, the 20-year leaching rate was selected to estimate long-term conditions. San Francisco and Newark were not available in the 5-year data base, but estimated leaching rates for both cities are presented using the 20-year data base.

With the inclusion of the 12 additional climatic centers, the greatest change in the leaching distributions was observed for Subtitle D facilities with estimated leaching rates greater than 7 inches. The leaching distribution from

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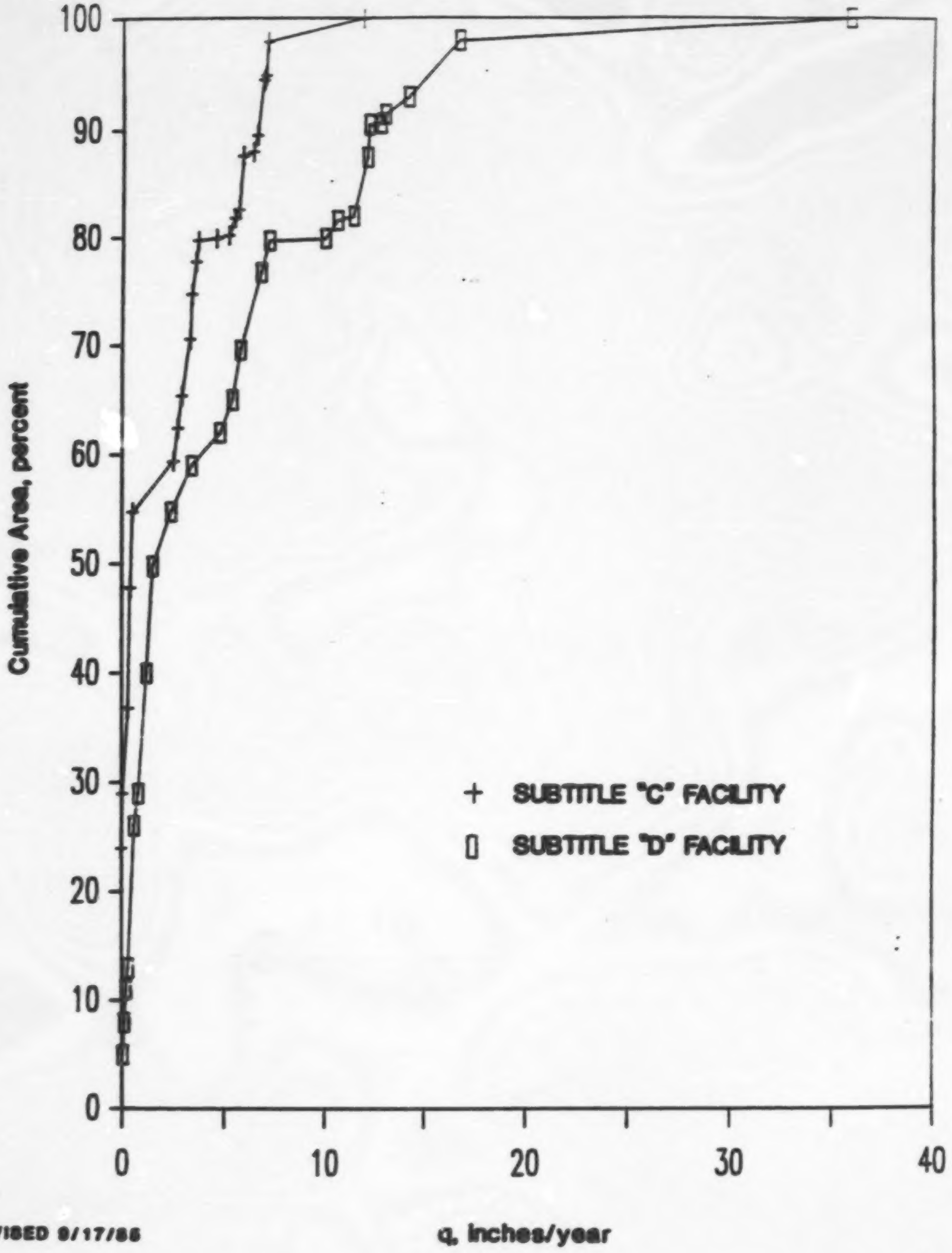

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FIGURE 2-1
ESTIMATED DISTRIBUTION OF UNIT AREA LEACHING RATES FOR SUBTITLE C AND D FACILITIES

E.C.JORDAN CO.

APPENDIX C

TABLES OF DILUTION FACTOR ζ^* VERSUS x/B

TABLE 1: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.500E-01

X/B-Value	B/ALFAz = 0.500E 01 Zeta-Value	B/ALFAz = 0.100E 02 Zeta-Value	B/ALFAz = 0.150E 02 Zeta-Value	B/ALFAz = 0.250E 02 Zeta-Value
0.10000E 00	0.35931E 00	0.47179E 00	0.54392E 00	0.63613E 00
0.15000E 00	0.26821E 00	0.36268E 00	0.42835E 00	0.51969E 00
0.20000E 00	0.21738E 00	0.29757E 00	0.35546E 00	0.43971E 00
0.30000E 00	0.16260E 00	0.22462E 00	0.27087E 00	0.34104E 00
0.40000E 00	0.13330E 00	0.18469E 00	0.22353E 00	0.28349E 00
0.50000E 00	0.11487E 00	0.15927E 00	0.19311E 00	0.24581E 00
0.60000E 00	0.10212E 00	0.14152E 00	0.17175E 00	0.21910E 00
0.70000E 00	0.92725E-01	0.12832E 00	0.15582E 00	0.19905E 00
0.80000E 00	0.85516E-01	0.11808E 00	0.14342E 00	0.18338E 00
0.90000E 00	0.79812E-01	0.10986E 00	0.13345E 00	0.17074E 00
0.10000E 01	0.75200E-01	0.10309E 00	0.12522E 00	0.16029E 00
0.15000E 01	0.61483E-01	0.81532E-01	0.98720E-01	0.12646E 00
0.20000E 01	0.55408E-01	0.69965E-01	0.84021E-01	0.10748E 00
0.25000E 01	0.52562E-01	0.62952E-01	0.74579E-01	0.95013E-01
0.30000E 01	0.51213E-01	0.58483E-01	0.68056E-01	0.86090E-01
0.40000E 01	0.50271E-01	0.53669E-01	0.59951E-01	0.74081E-01
0.50000E 01	0.50060E-01	0.51589E-01	0.55534E-01	0.66450E-01
0.60000E 01	0.50013E-01	0.50687E-01	0.53084E-01	0.61344E-01
0.70000E 01	0.50003E-01	0.50297E-01	0.51718E-01	0.57852E-01
0.80000E 01	0.50001E-01	0.50128E-01	0.50957E-01	0.55442E-01
0.90000E 01	0.50000E-01	0.50055E-01	0.50533E-01	0.53773E-01
0.10000E 02	0.50000E-01	0.50024E-01	0.50296E-01	0.52617E-01
0.15000E 02	0.50000E-01	0.50000E-01	0.50016E-01	0.50419E-01
0.20000E 02	0.50000E-01	0.50000E-01	0.50001E-01	0.50067E-01
0.30000E 02	0.50000E-01	0.50000E-01	0.50000E-01	0.50002E-01
0.40000E 02	0.50000E-01	0.50000E-01	0.50000E-01	0.50000E-01
0.50000E 02	0.50000E-01	0.50000E-01	0.50000E-01	0.50000E-01
0.60000E 02	0.50000E-01	0.50000E-01	0.50000E-01	0.50000E-01
0.70000E 02	0.50000E-01	0.50000E-01	0.50000E-01	0.50000E-01
0.80000E 02	0.50000E-01	0.50000E-01	0.50000E-01	0.50000E-01
0.90000E 02	0.50000E-01	0.50000E-01	0.50000E-01	0.50000E-01
0.10000E 03	0.50000E-01	0.50000E-01	0.50000E-01	0.50000E-01

TABLE 2: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.500E-01

X/B-Value	B/ALFAz = 0.350E 02 Zeta-Value	B/ALFAz = 0.500E 02 Zeta-Value	B/ALFAz = 0.750E 02 Zeta-Value	B/ALFAz = 0.100E 03 Zeta-Value
0.10000E 00	0.69468E 00	0.75253E 00	0.81109E 00	0.84725E 00
0.15000E 00	0.58286E 00	0.64986E 00	0.72285E 00	0.77076E 00
0.20000E 00	0.50102E 00	0.56926E 00	0.64796E 00	0.70235E 00
0.30000E 00	0.39475E 00	0.45777E 00	0.53563E 00	0.59338E 00
0.40000E 00	0.33043E 00	0.38690E 00	0.45920E 00	0.51498E 00
0.50000E 00	0.28755E 00	0.33845E 00	0.40495E 00	0.45747E 00
0.60000E 00	0.25685E 00	0.30326E 00	0.36464E 00	0.41386E 00
0.70000E 00	0.23367E 00	0.27646E 00	0.33352E 00	0.37971E 00
0.80000E 00	0.21548E 00	0.25530E 00	0.30870E 00	0.35223E 00
0.90000E 00	0.20077E 00	0.23811E 00	0.28839E 00	0.32960E 00
0.10000E 01	0.18857E 00	0.22382E 00	0.27143E 00	0.31060E 00
0.15000E 01	0.14899E 00	0.17721E 00	0.21564E 00	0.24758E 00
0.20000E 01	0.12669E 00	0.15082E 00	0.18380E 00	0.21134E 00
0.25000E 01	0.11200E 00	0.13340E 00	0.16271E 00	0.18723E 00
0.30000E 01	0.10142E 00	0.12083E 00	0.14746E 00	0.16977E 00
0.40000E 01	0.86975E-01	0.10359E 00	0.12649E 00	0.14572E 00
0.50000E 01	0.77452E-01	0.92091E-01	0.11246E 00	0.12961E 00
0.60000E 01	0.70704E-01	0.83761E-01	0.10225E 00	0.11786E 00
0.70000E 01	0.65738E-01	0.77416E-01	0.94390E-01	0.10881E 00
0.80000E 01	0.62011E-01	0.72430E-01	0.88113E-01	0.10157E 00
0.90000E 01	0.59184E-01	0.68434E-01	0.82964E-01	0.95599E-01
0.10000E 02	0.57029E-01	0.65190E-01	0.78655E-01	0.90578E-01
0.15000E 02	0.51851E-01	0.55856E-01	0.64758E-01	0.73862E-01
0.20000E 02	0.50487E-01	0.52268E-01	0.57751E-01	0.64538E-01
0.30000E 02	0.50034E-01	0.50340E-01	0.52152E-01	0.55509E-01
0.40000E 02	0.50002E-01	0.50051E-01	0.50598E-01	0.52094E-01
0.50000E 02	0.50000E-01	0.50008E-01	0.50166E-01	0.50796E-01
0.60000E 02	0.50000E-01	0.50001E-01	0.50046E-01	0.50303E-01
0.70000E 02	0.50000E-01	0.50000E-01	0.50013E-01	0.50115E-01
0.80000E 02	0.50000E-01	0.50000E-01	0.50004E-01	0.50044E-01
0.90000E 02	0.50000E-01	0.50000E-01	0.50001E-01	0.50017E-01
0.10000E 03	0.50000E-01	0.50000E-01	0.50000E-01	0.50006E-01

TABLE 3: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.100E 00

X/B-Value	B/ALFAz = 0.500E 01 Zeta-Value	B/ALFAz = 0.100E 02 Zeta-Value	B/ALFAz = 0.150E 02 Zeta-Value	B/ALFAz = 0.250E 02 Zeta-Value
0.10000E 00	0.60207E 00	0.72059E 00	0.78246E 00	0.84875E 00
0.15000E 00	0.48521E 00	0.61228E 00	0.68640E 00	0.77272E 00
0.20000E 00	0.40771E 00	0.53067E 00	0.60808E 00	0.70459E 00
0.30000E 00	0.31449E 00	0.42193E 00	0.49555E 00	0.59585E 00
0.40000E 00	0.26105E 00	0.35478E 00	0.42173E 00	0.51748E 00
0.50000E 00	0.22637E 00	0.30953E 00	0.37038E 00	0.45991E 00
0.60000E 00	0.20197E 00	0.27693E 00	0.33268E 00	0.41621E 00
0.70000E 00	0.18383E 00	0.25223E 00	0.30378E 00	0.38196E 00
0.80000E 00	0.16981E 00	0.23281E 00	0.28085E 00	0.35438E 00
0.90000E 00	0.15868E 00	0.21708E 00	0.26216E 00	0.33166E 00
0.10000E 01	0.14965E 00	0.20405E 00	0.24659E 00	0.31257E 00
0.15000E 01	0.12267E 00	0.16211E 00	0.19568E 00	0.24921E 00
0.20000E 01	0.11068E 00	0.13939E 00	0.16701E 00	0.21275E 00
0.25000E 01	0.10506E 00	0.12557E 00	0.14848E 00	0.18854E 00
0.30000E 01	0.10240E 00	0.11675E 00	0.13564E 00	0.17110E 00
0.40000E 01	0.10054E 00	0.10725E 00	0.11965E 00	0.14752E 00
0.50000E 01	0.10012E 00	0.10314E 00	0.11093E 00	0.13248E 00
0.60000E 01	0.10003E 00	0.10136E 00	0.10609E 00	0.12240E 00
0.70000E 01	0.10001E 00	0.10059E 00	0.10339E 00	0.11551E 00
0.80000E 01	0.10000E 00	0.10025E 00	0.10189E 00	0.11075E 00
0.90000E 01	0.10000E 00	0.10011E 00	0.10105E 00	0.10745E 00
0.10000E 02	0.10000E 00	0.10005E 00	0.10059E 00	0.10517E 00
0.15000E 02	0.10000E 00	0.10000E 00	0.10003E 00	0.10083E 00
0.20000E 02	0.10000E 00	0.10000E 00	0.10000E 00	0.10013E 00
0.30000E 02	0.10000E 00	0.10000E 00	0.10000E 00	0.10000E 00
0.40000E 02	0.10000E 00	0.10000E 00	0.10000E 00	0.10000E 00
0.50000E 02	0.10000E 00	0.10000E 00	0.10000E 00	0.10000E 00
0.60000E 02	0.10000E 00	0.10000E 00	0.10000E 00	0.10000E 00
0.70000E 02	0.10000E 00	0.10000E 00	0.10000E 00	0.10000E 00
0.80000E 02	0.10000E 00	0.10000E 00	0.10000E 00	0.10000E 00
0.90000E 02	0.10000E 00	0.10000E 00	0.10000E 00	0.10000E 00
0.10000E 03	0.10000E 00	0.10000E 00	0.10000E 00	0.10000E 00

TABLE 4: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.100E 00

X/B-Value	B/ALFAz = 0.350E 02 Zeta-Value	B/ALFAz = 0.500E 02 Zeta-Value	B/ALFAz = 0.750E 02 Zeta-Value	B/ALFAz = 0.100E 03 Zeta-Value
0.10000E 00	0.88461E 00	0.91587E 00	0.94358E 00	0.95872E 00
0.15000E 00	0.82261E 00	0.86804E 00	0.90987E 00	0.93338E 00
0.20000E 00	0.76389E 00	0.82038E 00	0.87463E 00	0.90611E 00
0.30000E 00	0.66333E 00	0.73265E 00	0.80472E 00	0.84945E 00
0.40000E 00	0.58555E 00	0.65925E 00	0.74080E 00	0.79440E 00
0.50000E 00	0.52576E 00	0.59961E 00	0.68509E 00	0.74390E 00
0.60000E 00	0.47901E 00	0.55116E 00	0.63743E 00	0.69888E 00
0.70000E 00	0.44165E 00	0.51137E 00	0.59676E 00	0.65922E 00
0.80000E 00	0.41113E 00	0.47825E 00	0.56192E 00	0.62438E 00
0.90000E 00	0.38573E 00	0.45027E 00	0.53184E 00	0.59371E 00
0.10000E 01	0.36423E 00	0.42633E 00	0.50566E 00	0.56660E 00
0.15000E 01	0.29192E 00	0.34430E 00	0.41325E 00	0.46818E 00
0.20000E 01	0,24976E 00	0.29558E 00	0.35671E 00	0.40624E 00
0.25000E 01	0.22155E 00	0.26269E 00	0.31799E 00	0.36321E 00
0.30000E 01	0.20106E 00	0.23865E 00	0.28946E 00	0.33125E 00
0.40000E 01	0.17286E 00	0.20532E 00	0.24960E 00	0.28629E 00
0.50000E 01	0.15416E 00	0.18289E 00	0.22258E 00	0.25563E 00
0.60000E 01	0.14087E 00	0.16657E 00	0.20275E 00	0.23304E 00
0.70000E 01	0.13108E 00	0.15410E 00	0.18741E 00	0.21552E 00
0.80000E 01	0.12372E 00	0.14428E 00	0.17512E 00	0.20143E 00
0.90000E 01	0.11814E 00	0.13640E 00	0.16501E 00	0.18979E 00
0.10000E 02	0.11388E 00	0.13000E 00	0.15654E 00	0.17996E 00
0.15000E 02	0.10366E 00	0.11157E 00	0.12915E 00	0.14711E 00
0.20000E 02	0.10096E 00	0.10448E 00	0.11531E 00	0.12871E 00
0.30000E 02	0.10007E 00	0.10067E 00	0.10425E 00	0.11088E 00
0.40000E 02	0.10000E 00	0.10010E 00	0.10118E 00	0.10414E 00
0.50000E 02	0.10000E 00	0.10002E 00	0.10033E 00	0.10157E 00
0.60000E 02	0.10000E 00	0.10000E 00	0.10009E 00	0.10060E 00
0.70000E 02	0.10000E 00	0.10000E 00	0.10003E 00	0.10023E 00
0.80000E 02	0.10000E 00	0,10000E 00	0.10001E 00	0.10009E 00
0.90000E 02	0.10000E 00	0.10000E 00	0.10000E 00	0.10003E 00
0.10000E 03	0.10000E 00	0.10000E 00	0.10000E 00	0.10001E 00

TABLE 5: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.150E 00

X/B-Value	B/ALFAz = 0.500E 01 Zeta-Value	B/ALFAz = 0.100E 02 Zeta-Value	B/ALFAz = 0.150E 02 Zeta-Value	B/ALFAz = 0.250E 02 Zeta-Value
0.10000E 00	0.74390E 00	0.83871E 00	0.88263E 00	0.92559E 00
0.15000E 00	0.63944E 00	0.75900E 00	0.81967E 00	0.88248E 00
0.20000E 00	0.55858E 00	0.68868E 00	0.76023E 00	0.83878E 00
0.30000E 00	0.44818E 00	0.57857E 00	0.65895E 00	0.75635E 00
0.40000E 00	0.37872E 00	0.50062E 00	0.58104E 00	0.68544E 00
0.50000E 00	0.33155E 00	0.44397E 00	0.52135E 00	0.62658E 00
0.60000E 00	0.29751E 00	0.40125E 00	0.47479E 00	0.57803E 00
0.70000E 00	0.27181E 00	0.36794E 00	0.43762E 00	0.53771E 00
0.80000E 00	0.25175E 00	0.34122E 00	0.40730E 00	0.50387E 00
0.90000E 00	0.23570E 00	0.31928E 00	0.38208E 00	0.47511E 00
0.10000E 01	0.22262E 00	0.30092E 00	0.36075E 00	0.45037E 00
0.15000E 01	0.18327E 00	0.24081E 00	0.28923E 00	0.36492E 00
0.20000E 01	0.16569E 00	0.20776E 00	0.24799E 00	0.31377E 00
0.25000E 01	0.[illegible]743E 00	0.18754E 00	0.22106E 00	0.27919E 00
0.30000E 01	0.15352E 00	0.17460E 00	0.20230E 00	0.25401E 00
0.40000E 01	0.15079E 00	0.16065E 00	0.17886E 00	0.21969E 00
0.50000E 01	0.15018E 00	0.15461E 00	0.16606E 00	0.19769E 00
0.60000E 01	0.15004E 00	0.15199E 00	0.15895E 00	0.18291E 00
0.70000E 01	0.15001E 00	0.15086E 00	0.15499E 00	0.17278E 00
0.80000E 01	0.15000E 00	0.15037E 00	0.15278E 00	0.16579E 00
0.90000E 01	0.15000E 00	0.15016E 00	0.15155E 00	0.16095E 00
0.10000E 02	0.15000E 00	0.15007E 00	0.15086E 00	0.15759E 00
0.15000E 02	0.15000E 00	0.15000E 00	0.15005E 00	0.15122E 00
0.20000E 02	0.15000E 00	0.15000E 00	0.15000E 00	0.15019E 00
0.30000E 02	0.15000E 00	0.15000E 00	0.15000E 00	0.15000E 00
0.40000E 02	0.15000E 00	0.15000E 00	0.15000E 00	0.15000E 00
0.50000E 02	0.15000E 00	0.15000E 00	0.15000E 00	0.15000E 00
0.60000E 02	0.15000E 00	0.15000E 00	0.15000E 00	0.15000E 00
0.70000E 02	0.15000E 00	0.15000E 00	0.15000E 00	0.15000E 00
0.80000E 02	0.15000E 00	0.15000E 00	0.15000E 00	0.15000E 00
0.90000E 02	0.15000E 00	0.15000E 00	0.15000E 00	0.15000E 00
0.10000E 03	0.15000E 00	0.15000E 00	0.15000E 00	0.15000E 00

TABLE 6: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.150E 00

X/B-Value	B/ALFAz = 0.350E 02 Zeta-Value	B/ALFAz = 0.500E 02 Zeta-Value	B/ALFAz = 0.750E 02 Zeta-Value	B/ALFAz = 0.100E 03 Zeta-Value
0.10000E 00	0.94693E 00	0.96427E 00	0.97841E 00	0.98548E 00
0.15000E 00	0.91499E 00	0.94208E 00	0.96461E 00	0.97607E 00
0.20000E 00	0.88137E 00	0.91793E 00	0.94916E 00	0.96534E 00
0.30000E 00	0.81403E 00	0.86680E 00	0.91465E 00	0.94062E 00
0.40000E 00	0.75171E 00	0.81587E 00	0.87762E 00	0.91283E 00
0.50000E 00	0.69686E 00	0.76812E 00	0.84034E 00	0.88352E 00
0.60000E 00	0.64956E 00	0.72475E 00	0.80434E 00	0.85394E 00
0.70000E 00	0.60898E 00	0.68598E 00	0.77044E 00	0.82498E 00
0.80000E 00	0.57404E 00	0.65152E 00	0.73897E 00	0.79718E 00
0.90000E 00	0.54378E 00	0.62090E 00	0.71000E 00	0.77085E 00
0.10000E 01	0.51736E 00	0.59362E 00	0.68344E 00	0.74610E 00
0.15000E 01	0.42363E 00	0.49320E 00	0.58005E 00	0.64487E 00
0.20000E 01	0.36599E 00	0.42906E 00	0.51004E 00	0.57258E 00
0.25000E 01	0.32641E 00	0.38418E 00	0.45956E 00	0.51894E 00
0.30000E 01	0.29724E 00	0.35070E 00	0.42122E 00	0.47749E 00
0.40000E 01	0.25660E 00	0.30344E 00	0.36624E 00	0.41713E 00
0.50000E 01	0.22940E 00	0.27118E 00	0.32815E 00	0.37479E 00
0.60000E 01	0.20998E 00	0.24751E 00	0.29984E 00	0.34306E 00
0.70000E 01	0.19563E 00	0.22934E 00	0.27776E 00	0.31817E 00
0.80000E 01	0.18484E 00	0.21498E 00	0.25997E 00	0.29800E 00
0.90000E 01	0.17665E 00	0.20344E 00	0.24527E 00	0.28122E 00
0.10000E 02	0.17040E 00	0.19405E 00	0.23292E 00	0.26701E 00
0.15000E 02	0.15537E 00	0.16699E 00	0.19281E 00	0.21914E 00
0.20000E 02	0.15141E 00	0.15658E 00	0.17249E 00	0.19217E 00
0.30000E 02	0.15010E 00	0.15099E 00	0.15625E 00	0.16599E 00
0.40000E 02	0.15001E 00	0.15015E 00	0.15173E 00	0.15608E 00
0.50000E 02	0.15000E 00	0.15002E 00	0.15048E 00	0.15231E 00
0.60000E 02	0.15000E 00	0.15000E 00	0.15013E 00	0.15088E 00
0.70000E 02	0.15000E 00	0.15000E 00	0.15004E 00	0.15033E 00
0.80000E 02	0.15000E 00	0.15000E 00	0.15001E 00	0.15013E 00
0.90000E 02	0.15000E 00	0.15000E 00	0.15000E 00	0.15005E 00
0.10000E 03	0.15000E 00	0.15000E 00	0.15000E 00	0.15002E 00

TABLE 7: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.250E 00

X/B-Value	B/ALFAz = 0.500E 01 Zeta-Value	B/ALFAz = 0.100E 02 Zeta-Value	B/ALFAz = 0.150E 02 Zeta-Value	B/ALFAz = 0.250E 02 Zeta-Value
0.10000E 00	0.87966E 00	0.93491E 00	0.95723E 00	0.97666E 00
0.15000E 00	0.81504E 00	0.89635E 00	0.93088E 00	0.96176E 00
0.20000E 00	0.75437E 00	0.85658E 00	0.90257E 00	0.94511E 00
0.30000E 00	0.65200E 00	0.77971E 00	0.84401E 00	0.90815E 00
0.40000E 00	0.57416E 00	0.71168E 00	0.78754E 00	0.86889E 00
0.50000E 00	0.51514E 00	0.65400E 00	0.73612E 00	0.82980E 00
0.60000E 00	0.46956E 00	0.60567E 00	0.69056E 00	0.79242E 00
0.70000E 00	0.43362E 00	0.56511E 00	0.65063E 00	0.75751E 00
0.80000E 00	0.40473E 00	0.53080E 00	0.61570E 00	0.72535E 00
0.90000E 00	0.38114E 00	0.50150E 00	0.58506E 00	0.69593E 00
0.10000E 01	0.36162E 00	0.47625E 00	0.55804E 00	0.66909E 00
0.15000E 01	0.30165E 00	0.38939E 00	0.46070E 00	0.56567E 00
0.20000E 01	0.27441E 00	0.33943E 00	0.40047E 00	0.49647E 00
0.25000E 01	0.26158E 00	0.30833E 00	0.35988E 00	0.44702E 00
0.30000E 01	0.25548E 00	0.28828E 00	0.33115E 00	0.40987E 00
0.40000E 01	0.25123E 00	0.26658E 00	0.29491E 00	0.35796E 00
0.50000E 01	0.25027E 00	0.25718E 00	0.27501E 00	0.32411E 00
0.60000E 01	0.25006E 00	0.25311E 00	0.26394E 00	0.30121E 00
0.70000E 01	0.25001E 00	0.25134E 00	0.25777E 00	0.28547E 00
0.80000E 01	0.25000E 00	0.25058E 00	0.25433E 00	0.27459E 00
0.90000E 01	0.25000E 00	0.25025E 00	0.25241E 00	0.26705E 00
0.10000E 02	0.25000E 00	0.25011E 00	0.25134E 00	0.26183E 00
0.15000E 02	0.25000E 00	0.25000E 00	0.25007E 00	0.25189E 00
0.20000E 02	0.25000E 00	0.25000E 00	0.25000E 00	0.25030E 00
0.30000E 02	0.25000E 00	0.25000E 00	0.25000E 00	0.25001E 00
0.40000E 02	0.25000E 00	0.25000E 00	0.25000E 00	0.25000E 00
0.50000E 02	0.25000E 00	0.25000E 00	0.25000E 00	0.25000E 00
0.60000E 02	0.25000E 00	0.25000E 00	0.25000E 00	0.25000E 00
0.70000E 02	0.25000E 00	0.25000E 00	0.25000E 00	0.25000E 00
0.80000E 02	0.25000E 00	0.25000E 00	0.25000E 00	0.25000E 00
0.90000E 02	0.25000E 00	0.25000E 00	0.25000E 00	0.25000E 00
0.10000E 03	0.25000E 00	0.25000E 00	0.25000E 00	0.25000E 00

TABLE 8: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.250E 00

X/B-Value	B/ALFAz = 0.350E 02 Zeta-Value	B/ALFAz = 0.500E 02 Zeta-Value	B/ALFAz = 0.750E 02 Zeta-Value	B/ALFAz = 0.100E 03 Zeta-Value
0.10000E 00	0.98518E 00	0.99134E 00	0.99568E 00	0.99752E 00
0.15000E 00	0.97555E 00	0.98564E 00	0.99279E 00	0.99586E 00
0.20000E 00	0.96457E 00	0.97903E 00	0.98940E 00	0.99388E 00
0.30000E 00	0.93930E 00	0.96329E 00	0.98108E 00	0.98895E 00
0.40000E 00	0.91093E 00	0.94474E 00	0.97081E 00	0.98270E 00
0.50000E 00	0.88109E 00	0.92416E 00	0.95881E 00	0.97515E 00
0.60000E 00	0.85105E 00	0.90234E 00	0.94539E 00	0.96642E 00
0.70000E 00	0.82171E 00	0.87998E 00	0.93088E 00	0.95667E 00
0.80000E 00	0.79362E 00	0.85762E 00	0.91564E 00	0.94606E 00
0.90000E 00	0.76705E 00	0.83564E 00	0.89995E 00	0.93478E 00
0.10000E 01	0.74213E 00	0.81431E 00	0.88408E 00	0.92301E 00
0.15000E 01	0.64054E 00	0.72090E 00	0.80745E 00	0.86165E 00
0.20000E 01	0.56830E 00	0.64891E 00	0.74135E 00	0.80352E 00
0.25000E 01	0.51482E 00	0.59314E 00	0.68654E 00	0.75232E 00
0.30000E 01	0.47360E 00	0.54888E 00	0.64110E 00	0.70812E 00
0.40000E 01	0.41398E 00	0.48295E 00	0.57062E 00	0.63693E 00
0.50000E 01	0.37290E 00	0.43591E 00	0.51848E 00	0.58252E 00
0.60000E 01	0.34313E 00	0.40049E 00	0.47815E 00	0.53957E 00
0.70000E 01	0.32096E 00	0.37289E 00	0.44588E 00	0.50468E 00
0.80000E 01	0.30422E 00	0.35087E 00	0.41940E 00	0.47568E 00
0.90000E 01	0.29149E 00	0.33306E 00	0.39724E 00	0.45113E 00
0.10000E 02	0.28176E 00	0.31853E 00	0.37845E 00	0.43004E 00
0.15000E 02	0.25837E 00	0.27646E 00	0.31661E 00	0.35734E 00
0.20000E 02	0.25220E 00	0.26025E 00	0.28503E 00	0.31563E 00
0.30000E 02	0.25015E 00	0.25154E 00	0.25973E 00	0.27490E 00
0.40000E 02	0.25001E 00	0.25023E 00	0.25270E 00	0.25947E 00
0.50000E 02	0.25000E 00	0.25003E 00	0.25075E 00	0.25360E 00
0.60000E 02	0.25000E 00	0.25001E 00	0.25021E 00	0.25137E 00
0.70000E 02	0.25000E 00	0.25000E 00	0.25006E 00	0.25052E 00
0.80000E 02	0.25000E 00	0.25000E 00	0.25002E 00	0.25020E 00
0.90000E 02	0.25000E 00	0.25000E 00	0.25000E 00	0.25008E 00
0.10000E 03	0.25000E 00	0.25000E 00	0.25000E 00	0.25003E 00

TABLE 9: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.375E 00

X/B-Value	B/ALFAz = 0.500E 01 Zeta-Value	B/ALFAz = 0.100E 02 Zeta-Value	B/ALFAz = 0.150E 02 Zeta-Value	B/ALFAz = 0.250E 02 Zeta-Value
0.10000E 00	0.94506E 00	0.97443E 00	0.98494E 00	0.99306E 00
0.15000E 00	0.91164E 00	0.95806E 00	0.97511E 00	0.98845E 00
0.20000E 00	0.87650E 00	0.93983E 00	0.96390E 00	0.98307E 00
0.30000E 00	0.80670E 00	0.89966E 00	0.93804E 00	0.97011E 00
0.40000E 00	0.74306E 00	0.85756E 00	0.90906E 00	0.95455E 00
0.50000E 00	0.68801E 00	0.81623E 00	0.87863E 00	0.93696E 00
0.60000E 00	0.64139E 00	0.77725E 00	0.84810E 00	0.91797E 00
0.70000E 00	0.60214E 00	0.74132E 00	0.81836E 00	0.89816E 00
0.80000E 00	0.56910E 00	0.70860E 00	0.78997E 00	0.87803E 00
0.90000E 00	0.54119E 00	0.67900E 00	0.76320E 00	0.85796E 00
0.10000E 01	0.51753E 00	0.65228E 00	0.73816E 00	0.83823E 00
0.15000E 01	0.44209E 00	0.55258E 00	0.63705E 00	0.74929E 00
0.20000E 01	0.40685E 00	0.49064E 00	0.56679E 00	0.67862E 00
0.25000E 01	0.39012E 00	0.45087E 00	0.51674E 00	0.62315E 00
0.30000E 01	0.38217E 00	0.42493E 00	0.48033E 00	0.57909E 00
0.40000E 01	0.37660E 00	0.39665E 00	0.43357E 00	0.51473E 00
0.50000E 01	0.37536E 00	0.38438E 00	0.40766E 00	0.47145E 00
0.60000E 01	0.37508E 00	0.37906E 00	0.39321E 00	0.44180E 00
0.70000E 01	0.37502E 00	0.37675E 00	0.38515E 00	0.42131E 00
0.80000E 01	0.37500E 00	0.37576E 00	0.38065E 00	0.40712E 00
0.90000E 01	0.37500E 00	0.37533E 00	0.37815E 00	0.39728E 00
0.10000E 02	0.37500E 00	0.37514E 00	0.37675E 00	0.39045E 00
0.15000E 02	0.37500E 00	0.37500E 00	0.37509E 00	0.37747E 00
0.20000E 02	0.37500E 00	0.37500E 00	0.37500E 00	0.37540E 00
0.30000E 02	0.37500E 00	0.37500E 00	0.37500E 00	0.37501E 00
0.40000E 02	0.37500E 00	0.37500E 00	0.37500E 00	0.37500E 00
0.50000E 02	0.37500E 00	0.37500E 00	0.37500E 00	0.37500E 00
0.60000E 02	0.37500E 00	0.37500E 00	0.37500E 00	0.37500E 00
0.70000E 02	0.37500E 00	0.37500E 00	0.37500E 00	0.37500E 00
0.80000E 02	0.37500E 00	0.37500E 00	0.37500E 00	0.37500E 00
0.90000E 02	0.37500E 00	0.37500E 00	0.37500E 00	0.37500E 00
0.10000E 03	0.37500E 00	0.37500E 00	0.37500E 00	0.37500E 00

TABLE 10: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.375E 00

X/B-Value	B/ALFAz = 0.350E 02 Zeta-Value	B/ALFAz = 0.500E 02 Zeta-Value	B/ALFAz = 0.750E 02 Zeta-Value	B/ALFAz = 0.100E 03 Zeta-Value
0.10000E 00	0.99615E 00	0.99810E 00	0.99925E 00	0.99964E 00
0.15000E 00	0.99357E 00	0.99682E 00	0.99873E 00	0.99940E 00
0.20000E 00	0.99053E 00	0.99529E 00	0.99812E 00	0.99911E 00
0.30000E 00	0.98302E 00	0.99145E 00	0.99655E 00	0.99835E 00
0.40000E 00	0.97368E 00	0.98652E 00	0.99446E 00	0.99733E 00
0.50000E 00	0.96269E 00	0.98049E 00	0.99183E 00	0.99601E 00
0.60000E 00	0.95029E 00	0.97342E 00	0.98862E 00	0.99437E 00
0.70000E 00	0.93679E 00	0.96540E 00	0.98483E 00	0.99238E 00
0.80000E 00	0.92251E 00	0.95655E 00	0.98046E 00	0.99002E 00
0.90000E 00	0.90771E 00	0.94701E 00	0.97555E 00	0.98730E 00
0.10000E 01	0.89263E 00	0.93692E 00	0.97013E 00	0.98421E 00
0.15000E 01	0.81879E 00	0.88243E 00	0.93726E 00	0.96385E 00
0.20000E 01	0.75398E 00	0.82852E 00	0.89939E 00	0.93755E 00
0.25000E 01	0.69971E 00	0.77962E 00	0.86108E 00	0.90846E 00
0.30000E 01	0.65452E 00	0.73658E 00	0.82459E 00	0.87882E 00
0.40000E 01	0.58459E 00	0.66602E 00	0.75990E 00	0.82245E 00
0.50000E 01	0.53379E 00	0.61149E 00	0.70614E 00	0.77253E 00
0.60000E 01	0.49598E 00	0.56848E 00	0.66143E 00	0.72922E 00
0.70000E 01	0.46744E 00	0.53400E 00	0.62389E 00	0.69171E 00
0.80000E 01	0.44573E 00	0.50602E 00	0.59203E 00	0.65905E 00
0.90000E 01	0.42916E 00	0.48314E 00	0.56474E 00	0.63043E 00
0.10000E 02	0.41648E 00	0.46435E 00	0.54120E 00	0.60519E 00
0.15000E 02	0.38593E 00	0.40957E 00	0.46188E 00	0.51446E 00
0.20000E 02	0.37788E 00	0.38839E 00	0.42075E 00	0.46063E 00
0.30000E 02	0.37520E 00	0.37701E 00	0.38771E 00	0.40753E 00
0.40000E 02	0.37501E 00	0.37530E 00	0.37853E 00	0.38737E 00
0.50000E 02	0.37500E 00	0.37504E 00	0.37598E 00	0.37970E 00
0.60000E 02	0.37500E 00	0.37501E 00	0.37527E 00	0.37679E 00
0.70000E 02	0.37500E 00	0.37500E 00	0.37508E 00	0.37568E 00
0.80000E 02	0.37500E 00	0.37500E 00	0.37502E 00	0.37526E 00
0.90000E 02	0.37500E 00	0.37500E 00	0.37501E 00	0.37510E 00
0.10000E 03	0.37500E 00	0.37500E 00	0.37500E 00	0.37504E 00

TABLE 11: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.500E 00

X/B-Value	B/ALFAz = 0.500E 01 Zeta-Value	B/ALFAz = 0.100E 02 Zeta-Value	B/ALFAz = 0.150E 02 Zeta-Value	B/ALFAz = 0.250E 02 Zeta-Value
0.10000E 00	0.97232E 00	0.98872E 00	0.99400E 00	0.99765E 00
0.15000E 00	0.95455E 00	0.98126E 00	0.98999E 00	0.99606E 00
0.20000E 00	0.93480E 00	0.97264E 00	0.98528E 00	0.99417E 00
0.30000E 00	0.89178E 00	0.95237E 00	0.97385E 00	0.98944E 00
0.40000E 00	0.84760E 00	0.92899E 00	0.95998E 00	0.98340E 00
0.50000E 00	0.80526E 00	0.90374E 00	0.94412E 00	0.97608E 00
0.60000E 00	0.76636E 00	0.87772E 00	0.92681E 00	0.96759E 00
0.70000E 00	0.73150E 00	0.85181E 00	0.90859E 00	0.95807E 00
0.80000E 00	0.70071E 00	0.82661E 00	0.88990E 00	0.94769E 00
0.90000E 00	0.67374E 00	0.80250E 00	0.87114E 00	0.93664E 00
0.10000E 01	0.65025E 00	0.77970E 00	0.85258E 00	0.92508E 00
0.15000E 01	0.57213E 00	0.68667E 00	0.76824E 00	0.86464E 00
0.20000E 01	0.53441E 00	0.62364E 00	0.70169E 00	0.80741E 00
0.25000E 01	0.51636E 00	0.58171E 00	0.65114E 00	0.75741E 00
0.30000E 01	0.50775E 00	0.55393E 00	0.61313E 00	0.71499E 00
0.40000E 01	0.50173E 00	0.52343E 00	0.56326E 00	0.64956E 00
0.50000E 01	0.50039E 00	0.51015E 00	0.53533E 00	0.60392E 00
0.60000E 01	0.50009E 00	0.50439E 00	0.51971E 00	0.57216E 00
0.70000E 01	0.50002E 00	0.50190E 00	0.51098E 00	0.55009E 00
0.80000E 01	0.50000E 00	0.50082E 00	0.50612E 00	0.53476E 00
0.90000E 01	0.50000E 00	0.50035E 00	0.50341E 00	0.52411E 00
0.10000E 02	0.50000E 00	0.50015E 00	0.50190E 00	0.51672E 00
0.15000E 02	0.50000E 00	0.50000E 00	0.50010E 00	0.50268E 00
0.20000E 02	0.50000E 00	0.50000E 00	0.50001E 00	0.50043E 00
0.30000E 02	0.50000E 00	0.50000E 00	0.50000E 00	0.50001E 00
0.40000E 02	0.50000E 00	0.50000E 00	0.50000E 00	0.50000E 00
0.50000E 02	0.50000E 00	0.50000E 00	0.50000E 00	0.50000E 00
0.60000E 02	0.50000E 00	0.50000E 00	0.50000E 00	0.50000E 00
0.70000E 02	0.50000E 00	0.50000E 00	0.50000E 00	0.50000E 00
0.80000E 02	0.50000E 00	0.50000E 00	0.50000E 00	0.50000E 00
0.90000E 02	0.50000E 00	0.50000E 00	0.50000E 00	0.50000E 00
0.10000E 03	0.50000E 00	0.50000E 00	0.50000E 00	0.50000E 00

TABLE 12: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.500E 00

X/B-Value	B/ALFAz = 0.350E 02 Zeta-Value	B/ALFAz = 0.500E 02 Zeta-Value	B/ALFAz = 0.750E 02 Zeta-Value	B/ALFAz = 0.100E 03 Zeta-Value
0.10000E 00	0.99886E 00	0.99952E 00	0.99985E 00	0.99994E 00
0.15000E 00	0.99808E 00	0.99920E 00	0.99975E 00	0.99990E 00
0.20000E 00	0.99715E 00	0.99880E 00	0.99962E 00	0.99985E 00
0.30000E 00	0.99478E 00	0.99779E 00	0.99929E 00	0.99972E 00
0.40000E 00	0.99168E 00	0.99643E 00	0.99884E 00	0.99954E 00
0.50000E 00	0.98781E 00	0.99469E 00	0.99825E 00	0.99930E 00
0.60000E 00	0.98316E 00	0.99253E 00	0.99750E 00	0.99899E 00
0.70000E 00	0.97776E 00	0.98994E 00	0.99657E 00	0.99860E 00
0.80000E 00	0.97165E 00	0.98690E 00	0.99545E 00	0.99811E 00
0.90000E 00	0.96490E 00	0.98343E 00	0.99411E 00	0.99752E 00
0.10000E 01	0.95759E 00	0.97953E 00	0.99255E 00	0.99682E 00
0.15000E 01	0.91548E 00	0.95464E 00	0.98139E 00	0.99140E 00
0.20000E 01	0.87028E 00	0.92389E 00	0.96517E 00	0.98255E 00
0.25000E 01	0.82696E 00	0.89110E 00	0.94536E 00	0.97058E 00
0.30000E 01	0.78746E 00	0.85865E 00	0.92354E 00	0.95621E 00
0.40000E 01	0.72107E 00	0.79895E 00	0.87837E 00	0.92337E 00
0.50000E 01	0.66964E 00	0.74803E 00	0.83517E 00	0.88881E 00
0.60000E 01	0.63009E 00	0.70547E 00	0.79581E 00	0.85512E 00
0.70000E 01	0.59973E 00	0.67012E 00	0.76066E 00	0.82344E 00
0.80000E 01	0.57644E 00	0.64082E 00	0.72953E 00	0.79415E 00
0.90000E 01	0.55857E 00	0.61655E 00	0.70205E 00	0.76732E 00
0.10000E 02	0.54488E 00	0.59646E 00	0.67784E 00	0.74283E 00
0.15000E 02	0.51183E 00	0.53741E 00	0.59386E 00	0.64994E 00
0.20000E 02	0.50311E 00	0.51450E 00	0.54950E 00	0.59252E 00
0.30000E 02	0.50022E 00	0.50217E 00	0.51376E 00	0.53520E 00
0.40000E 02	0.50001E 00	0.50033E 00	0.50382E 00	0.51339E 00
0.50000E 02	0.50000E 00	0.50005E 00	0.50106E 00	0.50509E 00
0.60000E 02	0.50000E 00	0.50001E 00	0.50029E 00	0.50193E 00
0.70000E 02	0.50000E 00	0.50000E 00	0.50008E 00	0.50073E 00
0.80000E 02	0.50000E 00	0.50000E 00	0.50002E 00	0.50028E 00
0.90000E 02	0.50000E 00	0.50000E 00	0.50001E 00	0.50011E 00
0.10000E 03	0.50000E 00	0.50000E 00	0.50000E 00	0.50004E 00

TABLE 13: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.600E 00

X/B-Value	B/ALFAz = 0.500E 01 Zeta-Value	B/ALFAz = 0.100E 02 Zeta-Value	B/ALFAz = 0.150E 02 Zeta-Value	B/ALFA = 0.250E 02 Zeta-Value
0.10000E 00	0.98345E 00	0.99387E 00	0.99698E 00	0.99896E 00
0.15000E 00	0.97256E 00	0.98976E 00	0.99494E 00	0.99825E 00
0.20000E 00	0.96015E 00	0.98493E 00	0.99252E 00	0.99739E 00
0.30000E 00	0.93186E 00	0.97321E 00	0.98648E 00	0.99522E 00
0.40000E 00	0.90089E 00	0.95903E 00	0.97887E 00	0.99236E 00
0.50000E 00	0.86938E 00	0.94290E 00	0.96977E 00	0.98877E 00
0.60000E 00	0.83888E 00	0.92542E 00	0.95937E 00	0.98445E 00
0.70000E 00	0.81035E 00	0.90716E 00	0.94792E 00	0.97941E 00
0.80000E 00	0.78428E 00	0.88861E 00	0.93565E 00	0.97369E 00
0.90000E 00	0.76082E 00	0.87018E 00	0.92281E 00	0.96735E 00
0.10000E 01	0.73996E 00	0.85217E 00	0.90963E 00	0.96046E 00
0.15000E 01	0.66823E 00	0.77347E 00	0.84427E 00	0.92054E 00
0.20000E 01	0.63268E 00	0.71644E 00	0.78746E 00	0.87756E 00
0.25000E 01	0.61555E 00	0.67739E 00	0.74203E 00	0.83668E 00
0.30000E 01	0.60737E 00	0.65120E 00	0.70692E 00	0.80005E 00
0.40000E 01	0.60165E 00	0.62228E 00	0.66006E 00	0.74096E 00
0.50000E 01	0.60037E 00	0.60966E 00	0.63358E 00	0.69846E 00
0.60000E 01	0.60008E 00	0.60418E 00	0.61874E 00	0.66853E 00
0.70000E 01	0.60002E 00	0.60181E 00	0.61044E 00	0.64761E 00
0.80000E 01	0.60000E 00	0.60078E 00	0.60582E 00	0.63305E 00
0.90000E 01	0.60000E 00	0.60034E 00	0.60324E 00	0.62293E 00
0.10000E 02	0.60000E 00	0.60014E 00	0.60180E 00	0.61590E 00
0.15000E 02	0.60000E 00	0.60000E 00	0.60010E 00	0.60255E 00
0.20000E 02	0.60000E 00	0.60000E 00	0.60001E 00	0.60041E 00
0.30000E 02	0.60000E 00	0.60000E 00	0.60000E 00	0.60001E 00
0.40000E 02	0.60000E 00	0.60000E 00	0.60000E 00	0.60000E 00
0.50000E 02	0.60000E 00	0.60000E 00	0.60000E 00	0.60000E 00
0.60000E 02	0.60000E 00	0.60000E 00	0.60000E 00	0.60000E 00
0.70000E 02	0.60000E 00	0.60000E 00	0.60000E 00	0.60000E 00
0.80000E 02	0.60000E 00	0.60000E 00	0.60000E 00	0.60000E 00
0.90000E 02	0.60000E 00	0.60000E 00	0.60000E 00	0.60000E 00
0.10000E 03	0.60000E 00	0.60000E 00	0.60000E 00	0.60000E 00

TABLE 14: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.600E 00

X/B-Value	B/ALFAz = 0.350E 02 Zeta-Value	B/ALFAz = 0.500E 02 Zeta-Value	B/ALFAz = 0.750E 02 Zeta-Value	B/ALFAz = 0.100E 03 Zeta-Value
0.10000E 00	0.99954E 00	0.99983E 00	0.99996E 00	0.99999E 00
0.15000E 00	0.99923E 00	0.99972E 00	0.99992E 00	0.99997E 00
0.20000E 00	0.99885E 00	0.99958E 00	0.99989E 00	0.99996E 00
0.30000E 00	0.99787E 00	0.99921E 00	0.99979E 00	0.99993E 00
0.40000E 00	0.99657E 00	0.99871E 00	0.99965E 00	0.99988E 00
0.50000E 00	0.99489E 00	0.99806E 00	0.99947E 00	0.99982E 00
0.60000E 00	0.99280E 00	0.99723E 00	0.99923E 00	0.99974E 00
0.70000E 00	0.99029E 00	0.99620E 00	0.99893E 00	0.99963E 00
0,80000E 00	0.98735E 00	0.99495E 00	0.99856E 00	0.99949E 00
0.90000E 00	0.98397E 00	0.99348E 00	0.99810E 00	0.99932E 00
0.10000E 01	0.98018E 00	0.99177E 00	0.99755E 00	0.99911E 00
0.15000E 01	0.95589E 00	0.97965E 00	0.99322E 00	0.99736E 00
0.20000E 01	0.92585E 00	0.96229E 00	0.98592E 00	0.99406E 00
0.25000E 01	0.89389E 00	0.94140E 00	0.97575E 00	0.98896E 00
0.30000E 01	0.86250E 00	0.91872E 00	0.96325E 00	0.98207E 00
0.40000E 01	0.80592E 00	0.87269E 00	0.93386E 00	0.96383E 00
0.50000E 01	0.75963E 00	0.82996E 00	0.90216E 00	0.94168E 00
0.60000E 01	0.72306E 00	0.79242E 00	0.87088E 00	0.91777E 00
0.70000E 01	0.69459E 00	0.76029E 00	0.84136E 00	0.89355E 00
0.80000E 01	0.67259E 00	0.73317E 00	0.81422E 00	0.86992E 00
0.90000E 01	0.65567E 00	0.71047E 00	0.78963E 00	0.84737E 00
0.10000E 02	0.64267E 00	0.69155E 00	0.76756E 00	0.82617E 00
0.15000E 02	0.61125E 00	0.63558E 00	0.68912E 00	0.74184E 00
0.20000E 02	0.60296E 00	0.61379E 00	0.64707E 00	0.68787E 00
0.30000E 02	0.60020E 00	0.60207E 00	0.61308E 00	0.63348E 00
0.40000E 02	0.60001E 00	0.60031E 00	0.60363E 00	0.61273E 00
0.50000E 02	0.60000E 00	0.60005E 00	0.60101E 00	0.60484E 00
0.60000E 02	0.60000E 00	0.60001E 00	0.60028E 00	0.60184E 00
0.70000E 02	0.60000E 00	0.60000E 00	0.60008E 00	0.60070E 00
0.80000E 02	0.60000E 00	0.60000E 00	0.60002E 00	0.60027E 00
0.90000E 02	0.60000E 00	0.60000E 00	0.60001E 00	0.60010E 00
0.10000E 03	0.60000E 00	0.60000E 00	0.60000E 00	0.60004E 00

TABLE 15: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.800E 00

X/B-Value	B/ALFAz = 0.500E 01 Zeta-Value	B/ALFAz = 0.100E 02 Zeta-Value	B/ALFAz = 0.150E 02 Zeta-Value	B/ALFAz = 0.250E 02 Zeta-Value
0.10000E 00	0.99440E 00	0.99822E 00	0.99923E 00	0.99979E 00
0.15000E 00	0.99063E 00	0.99701E 00	0.99870E 00	0.99964E 00
0.20000E 00	0.98621E 00	0.99556E 00	0.99807E 00	0.99946E 00
0.30000E 00	0.97562E 00	0.99191E 00	0.99644E 00	0.99899E 00
0.40000E 00	0.96316E 00	0.98726E 00	0.99429E 00	0.99836E 00
0.50000E 00	0.94951E 00	0.98164E 00	0.99159E 00	0.99754E 00
0.60000E 00	0.93537E 00	0.97515E 00	0.98834E 00	0.99650E 00
0.70000E 00	0.92135E 00	0.96795E 00	0.98453E 00	0.99522E 00
0.80000E 00	0.90788E 00	0.96020E 00	0.98022E 00	0.99370E 00
0.90000E 00	0.89528E 00	0.95208E 00	0.97546E 00	0.99193E 00
0.10000E 01	0.88371E 00	0.94375E 00	0.97031E 00	0.98989E 00
0.15000E 01	0.84180E 00	0.90336E 00	0.94115E 00	0.97620E 00
0.20000E 01	0.82015E 00	0.87084E 00	0.91170E 00	0.95825E 00
0.25000E 01	0.80961E 00	0.84751E 00	0.88609E 00	0.93864E 00
0.30000E 01	0.80456E 00	0.83155E 00	0.86541E 00	0.91938E 00
0.40000E 01	0.80102E 00	0.81376E 00	0.83702E 00	0.88586E 00
0.50000E 01	0.80023E 00	0.80597E 00	0.82074E 00	0.86049E 00
0.60000E 01	0.80005E 00	0.80258E 00	0.81158E 00	0.84225E 00
0.70000E 01	0.80001E 00	0.80112E 00	0.80645E 00	0.82939E 00
0.80000E 01	0.80000E 00	0.80048E 00	0.80360E 00	0.82042E 00
0.90000E 01	0.80000E 00	0.80021E 00	0.80200E 00	0.81417E 00
0.10000E 02	0.80000E 00	0.80009E 00	0.80111E 00	0.80983E 00
0.15000E 02	0.80000E 00	0.80000E 00	0.80006E 00	0.80157E 00
0.20000E 02	0.80000E 00	0.80000E 00	0.80000E 00	0.80025E 00
0.30000E 02	0.80000E 00	0.80000E 00	0.80000E 00	0.80001E 00
0.40000E 02	0.80000E 00	0.80000E 00	0.80000E 00	0.80000E 00
0.50000E 02	0.80000E 00	0.80000E 00	0.80000E 00	0.80000E 00
0.60000E 02	0.80000E 00	0.80000E 00	0.80000E 00	0.80000E 00
0.70000E 02	0.80000E 00	0.80000E 00	0.80000E 00	0.80000E 00
0.80000E 02	0.80000E 00	0.80000E 00	0.80000E 00	0.80000E 00
0.90000E 02	0.80000E 00	0.80000E 00	0.80000E 00	0.80000E 00
0.10000E 03	0.80000E 00	0.80000E 00	0.80000E 00	0.80000E 00

TABLE 16: Dilution Factor(ZETA) versus X/B for Penetration Ratio(H/B) = 0.800E 00

X/B-Value	B/ALFAz = 0.350E 02 Zeta-Value	B/ALFAz = 0.500E 02 Zeta-Value	B/ALFAz = 0.750E 02 Zeta-Value	B/ALFAz = 0.100E 03 Zeta-Value
0.10000E 00	0.99992E 00	0.99998E 00	0.10000E 01	0.10000E 01
0.15000E 00	0.99987E 00	0.99996E 00	0.99999E 00	0.10000E 01
0.20000E 00	0.99980E 00	0.99994E 00	0.99999E 00	0.10000E 01
0.30000E 00	0.99963E 00	0.99989E 00	0.99998E 00	0.10000E 01
0.40000E 00	0.99939E 00	0.99982E 00	0.99997E 00	0.99999E 00
0.50000E 00	0.99908E 00	0.99973E 00	0.99995E 00	0.99999E 00
0.60000E 00	0.99867E 00	0.99961E 00	0.99992E 00	0.99998E 00
0.70000E 00	0.99816E 00	0.99945E 00	0.99989E 00	0.99997E 00
0.80000E 00	0.99754E 00	0.99925E 00	0.99985E 00	0.99996E 00
0.90000E 00	0.99679E 00	0.99900E 00	0.99980E 00	0.99995E 00
0.10000E 01	0.99590E 00	0.99870E 00	0.99973E 00	0.99993E 00
0.15000E 01	0.98929E 00	0.99625E 00	0.99915E 00	0.99976E 00
0.20000E 01	0.97915E 00	0.99187E 00	0.99794E 00	0.99938E 00
0.25000E 01	0.96636E 00	0.98548E 00	0.99587E 00	0.99865E 00
0.30000E 01	0.95210E 00	0.97734E 00	0.99280E 00	0.99745E 00
0.40000E 01	0.92305E 00	0.95766E 00	0.98372E 00	0.99334E 00
0.50000E 01	0.89698E 00	0.93639E 00	0.97151E 00	0.98683E 00
0.60000E 01	0.87539E 00	0.91597E 00	0.95749E 00	0.97827E 00
0.70000E 01	0.85820E 00	0.89757E 00	0.94283E 00	0.96826E 00
0.80000E 01	0.84476E 00	0.88155E 00	0.92840E 00	0.95740E 00
0.90000E 01	0.83437E 00	0.86789E 00	0.91469E 00	0.94622E 00
0.10000E 02	0.82636E 00	0.85639E 00	0.90200E 00	0.93510E 00
0.15000E 02	0.80696E 00	0.82198E 00	0.85493E 00	0.88689E 00
0.20000E 02	0.80183E 00	0.80852E 00	0.82908E 00	0.85418E 00
0.30000E 02	0.80013E 00	0.80128E 00	0.80809E 00	0.82069E 00
0.40000E 02	0.80001E 00	0.80019E 00	0.80225E 00	0.80787E 00
0.50000E 02	0.80000E 00	0.80003E 00	0.80062E 00	0.80299E 00
0.60000E 02	0.80000E 00	0.80000E 00	0.80017E 00	0.80114E 00
0.70000E 02	0.80000E 00	0.80000E 00	0.80005E 00	0.80043E 00
0.80000E 02	0.80000E 00	0.80000E 00	0.80001E 00	0.80016E 00
0.90000E 02	0.80000E 00	0.80000E 00	0.80000E 00	0.80006E 00
0.10000E 03	0.80000E 00	0.80000E 00	0.80000E 00	0.80002E 00

=#40 #2 D

ANALYSIS OF ENGINEERED CONTROLS OF SUBTITLE C FACILITIES FOR LAND DISPOSAL RESTRICTIONS DETERMINATIONS

APPENDIX D

ANALYSIS OF ENGINEERED CONTROLS OF SUBTITLE C FACILITIES FOR LAND DISPOSAL RESTRICTIONS DETERMINATIONS

FINAL REPORT

Contract No. 68-01-7075
Work Assignment No. 24
RTI Project No. 3224
ECJ Project No. 4756-00

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1.0 INTRODUCTION

In accordance with recent federal legislation, land disposal of certain hazardous wastes is to be banned. Short-term hazards posed by these wastes can be controlled by specially engineered and constructed facilities. The banning of wastes is intended to prevent hazards posed by certain wastes as the long-term performance of the engineered facilities change. Analysis of these changes in long-term performance provides information needed to determine which wastes to ban.

1.1 Background

In accordance with the Resource Conservation and Recovery act of 1976 (RCRA) and the Solid Waste Amendments of 1984 (Amendments), the U.S. Environmental Protection Agency (EPA) must review all listed hazardous wastes and hazardous constituents and determine which wastes should be banned from hazardous waste land disposal facilities. The Amendments require waste to be banned for as long as the waste is hazardous if the wastes are highly mobile, highly toxic, persistent or bioaccumulate and pose a significant threat to human health and the environment. Further, the EPA is developing a complementary test, EP-III, for the toxicity characteristic of hazardous wastes. This test, similar to the existing test (EP-I) which screens wastes for the presence of selected mobile heavy metals and organic compounds (40 CFR 261.24), will screen wastes for the presence of other mobile organic constituents. Both tests are intended to be used by generators of solid wastes to determine if a waste is hazardous. While specific criteria were established (i.e., 100 times National Interim Primary Drinking Water Regulations) for the concentration of chemicals in the extract of EP-I, new criteria need to be identified for chemicals that exceed these criteria to determine if they should be banned from land disposal facilities. Criteria will also be needed for waste classification and banning for chemicals detected in the extract of EP-III.

The EPA, as part of a comprehensive regulatory development program to protect human health and the environment from mobile and toxic wastes has identified the following needs:

o identify wastes that should be classified hazardous and managed in Subtitle C (hazardous waste) facilities; and

o identify those wastes that should be banned from Subtitle C land disposal facilities.

Wastes that are not classified as hazardous may be managed in Subtitle D facilities such as sanitary landfills, municipal incinerators and resource recovery facilities.

EPA's Office of Solid Waste (OSW) is currently developing a framework for a regulatory program to address these needs. This proposed framework is intended to provide a generic screening procedure for all wastes generated in the United

States. Under OSW's proposed framework, EPA will establish screening levels for chemical constituents of wastes.

The screening levels will be transformed as maximum acceptable concentrations for chemicals in air emissions, surface runoff and leachate emanating from land disposal facilities. These transformed criteria will be established through a back-calculation procedure. This procedure uses fate and transport models that start from a point of potential chemical exposure at a concentration protective of public health and the environment and estimates the chemical concentration in leachate that will not cause the criterion to be exceeded. Wastes that yield a chemical concentration in the EP extract that exceeds the transformed criterion will be classified as hazardous.

The transformed criteria will be further adjusted to account for the additional control over hazardous wastes provided by engineered structures at Subtitle C land disposal facilities. If chemical concentrations in the EP extract exceed these adjusted criteria, then the waste would be banned from Subtitle C land disposal facilities.

Adjustments may be based on one or more of the following:

- leaching environment and chemical flux to air, surface water or groundwater;
- containment facilities (e.g., cover system, liner system); and

- management controls (e.g., groundwater monitoring, operating and post-closure care period procedures).

Leaching environments and chemical flux are highly site specific and waste specific. Further, the interaction of wastes and mobile constituents of wastes may significantly alter the chemical flux from a facility that occurs as precipitation (e.g., rainfall) percolates through the waste deposit. Increases in the chemical flux may occur by enhancing the solubility of a constituent by the presence of a mobile chemical from another waste in percolating precipitation. For example, hydrophobic chemicals may dissolve to a greater extent if the percolating water contains sufficient organic solvents to enhance the solubility of these chemicals. Decreases in chemical flux may occur due to waste-waste interactions or other physicochemical or biological activity that may occur during facility operation and containment of the waste after closure. Examples of processes that may reduce chemical flux to the environment include:

- collection of mobile chemicals in leachate during operations and post-closure care period (PCP):
- hydrolysis of organic wastes;
- waste/waste interactions;
- chemical, physical and/or biological transformation or degradation of hazardous constituents; and

- volatilization.

Management of land disposal facilities is typically more structured and controlled at Subtitle C facilities than at Subtitle D facilities. During operations, wastes are screened, analyzed, and, if appropriate, rejected to protect the performance of engineered containment systems and public health and the environment. Undesirable waste-waste interactions can also be avoided. Groundwater monitoring, inspection, maintenance and reporting enhance the intended performance of the facility. Contingency plans and a regulatory program for corrective action exist through the post-closure care period to prevent and control chemical flux from the facility.

A greater degree of containment is typically provided at Subtitle C facilities than at Subtitle D facilities. Installation and operation of leachate collection systems is specifically regulated. Cover and liner system components and performance are also specifically regulated. Engineered controls are specified in 40 CFR Parts 264 and 265 for Subtitle C and in 40 CFR 257 for Subtitle D land disposal facilities.

1.2 Objective

The objective of this report is to identify how these engineered controls can be incorporated into the back-calculation procedure. Engineered controls will be analyzed and evaluated to factor these controls into OSW's approach for for restricting land disposal of hazardous waste.

The analysis takes into account the time importance of low permeable barrier layers in cover and liner systems (e.g., polymeric geomembranes, clay), leachate collection and removal systems, groundwater monitoring and corrective action requirements of 40 CFR Parts 264 and 265. Particular emphasis is placed on long-term events and performance of these control systems.

OSW's proposed regulatory framework is intended to provide a generic screening procedure, independent of site specific factors and protective of human health and the environment. The analysis and evaluation was conducted on a national scale to incorporate engineered controls into OSW's proposed regulatory framework.

1.3 General Approach

A procedure to incorporate engineering controls into OSW's proposed regulatory framework needs to consider the following factors:

- chemical flux depends on the presence of a transport medium and the leachability of specific chemicals in that medium; and
- performance of engineered controls depends on duration of exposure to natural weathering processes and chemicals contained.

Chemical flux to groundwater from a land disposal facility occurs as a result of chemicals dissolving into liquids migrating through the waste. Since bulk and containerized liquid wastes are currently banned from land disposal facilities, chemical flux is the result of precipitation that percolates through the waste.

Performance of engineered control structures in the short-term depends on appropriate design, material selection and specification, construction, waste screening, inspection, maintenance and monitoring. Over time, performance characteristics of cover or liner system components can be expected to change. Some components, such as polymeric geomembranes, may undergo dramatic change in performance while other components, such as clay layers, may undergo more limited change in performance. The effect these changes have on component and system performance will control the leaching rate and thus the mass and concentration of chemical leached.

Duration of containment is important for evaluating the threat posed by hazardous wastes if the processes identified in Section 1.1 can be reasonably expected to significantly reduce mobility, toxicity or tendency to bioaccumulate during the containment period. Currently, there is insufficient information available to accurately account for such significant reductions in waste characteristics in a generic screening procedure. Where information is available, then the generator may seek a variance through a site-specific petition procedure.

The back-calculation procedure proposed by OSW incorporates several important characteristics:

- the procedure should not be dependent on a limited mass of waste (the procedure does not limit hazards due to the size of a facility or the quantity of waste deposited in a facility); and

- the procedure is independent of long-term (on the order of thousands of years) events or changes in facility performance.

These characteristics indicate that short-term performance of engineered control, such as during operations or the typical 30 year PCP, are not important in transforming the screening levels to classification and banning criteria. The most important characteristic is the leachate rate caused by precipitation percolating through the waste.

Land disposal facilities typically include:

- waste piles;
- surface impoundments;
- landfill;
- land treatment; and
- subsurface injection well facilities.

Requirements of 40 CFR Parts 264 and 265 state that closure of waste piles and subsurface impoundments must remove all hazardous waste or close in compliance with all landfill regulations. Due to the long-term characteristic of the screening procedure, only closed landfills are considered in assessing engineered controls. Land treatment and subsurface injection well facilities represent special cases and are not considered in this analysis.

Analysis and evaluation of engineered controls at land disposal facilities were incorporated into the proposed regulatory framework by the following approach:

- identify significant mechanisms and extent of changes in leaching rates from Subtitle C and D facilities;
- determine long-term leaching rates representative of climatic and site conditions within the contiguous 48 states for Subtitle C and D facilities;
- develop an area weighted distribution of leaching rates; and
- conduct a sensitivity analysis of the parameters used to estimate the leaching rates.

This approach was selected because the primary transport mechanism to the groundwater is percolating precipitation, long-term performance will yield the greatest chemical flux to the groundwater, and the procedure should be generic.

2.0 ANALYTICAL APPROACH

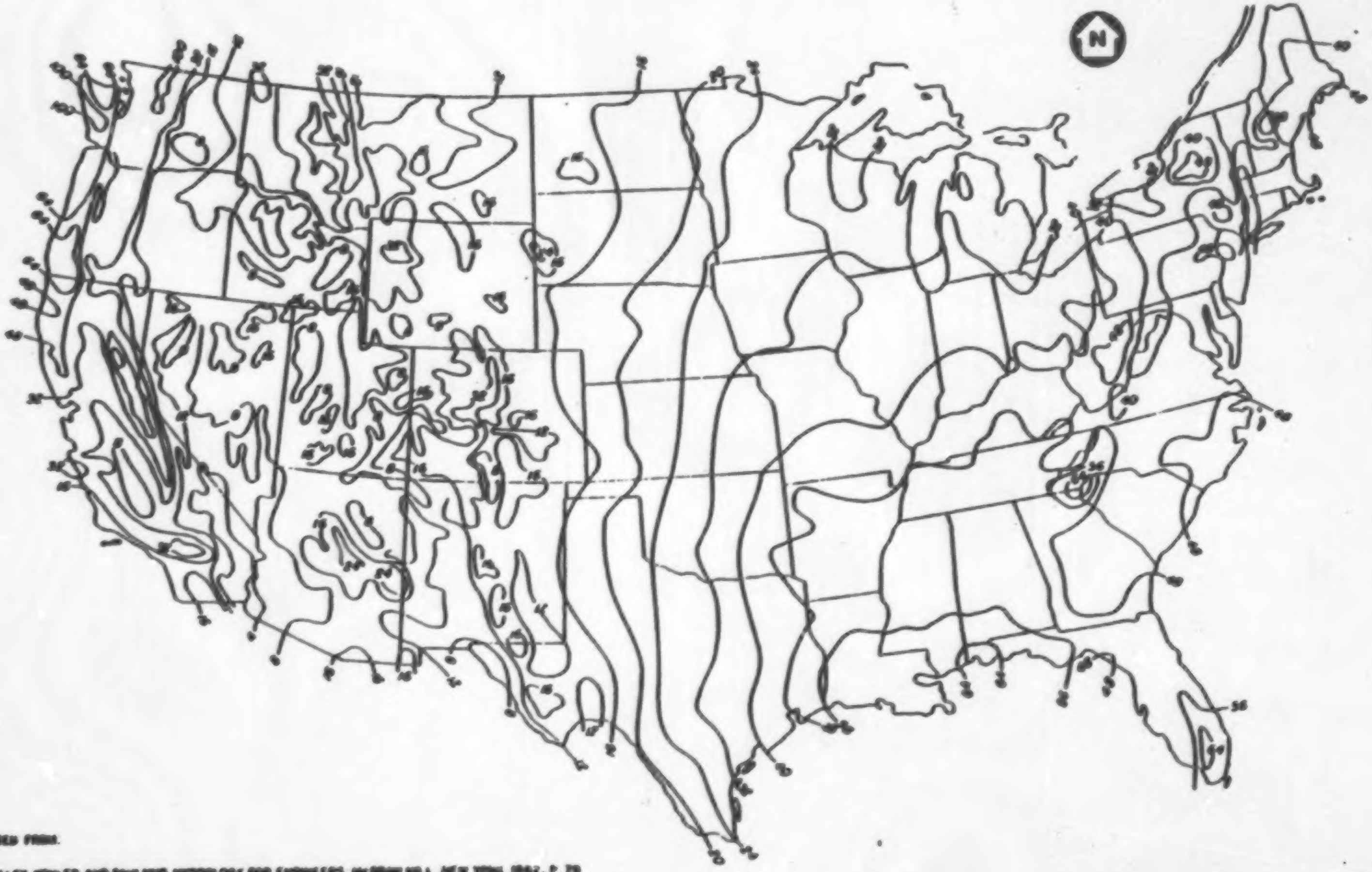
The analytical approach used to incorporate engineered controls into land disposal restrictions is based on the leaching process and anticipated long-term conditions at the disposal facility. A standard set of conditions is used to develop national leaching rate distributions for Subtitle C and D facilities. Sensitivity analysis of the standard conditions describes the potential variation for each distribution.

2.1 Leaching Process

Long-term chemical flux at land disposal sites is caused by precipitation percolating through the waste. The leaching process depends on regional climatic conditions and site specific facility conditions. Quantitative estimates of long-term leaching rates can be made using historic climatic and anticipated facility conditions.

2.1.1 Climatic Conditions

Distribution of precipitation in the contiguous 48 states is shown in Figure 2-1. Precipitation will vary from year to year, but typically will vary less than 20 percent of the average precipitation. Precipitation in the form of rainfall will initially enter or infiltrate the cover soil of a disposal facility until the precipitation rate exceeds the infiltration rate and will then drain from the facility as surface runoff. Water that infiltrates the sur-



ADAPTED FROM:

LINSLEY, KOHLER, AND PAULHUS, HYDROLOGY FOR ENGINEERS, McGRAW HILL, NEW YORK, 1982, P. 79

FIGURE 2-1

MEAN ANNUAL PRECIPITATION (IN INCHES)

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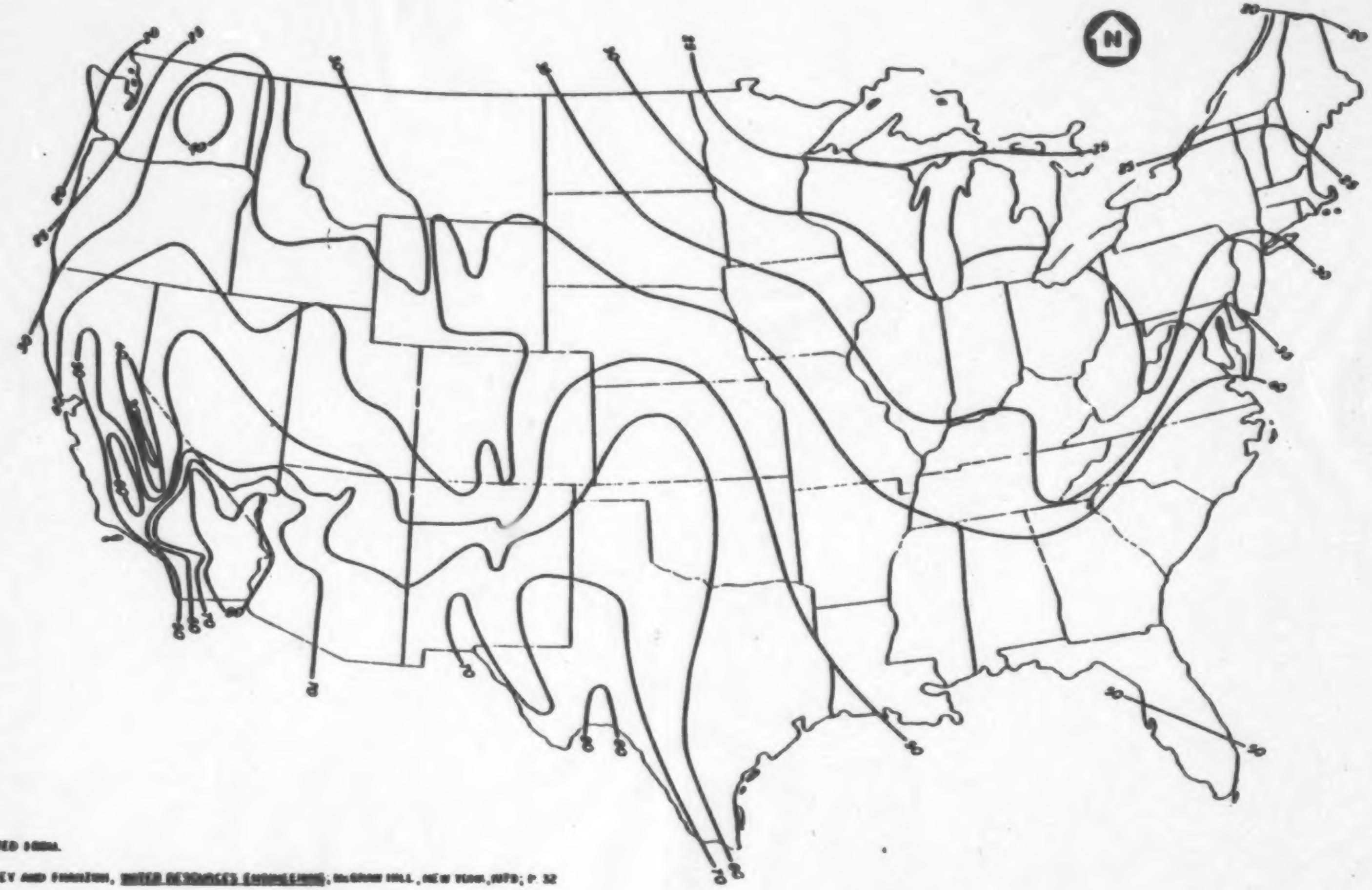
face soil is stored in the soil and transmitted to lower, less moist soils. Infiltrating water is removed from the soil through evaporation and transpiration. Average evaporative losses are shown in Figure 2-2. Evaporative losses from pans or lakes are used because of the difficulty in directly measuring evaporation and transpiration losses from soil. Areas with high evaporative losses are also found to have high evaporative-transpiration (E-T) losses. Actual E-T losses will depend on such factors as solar radiation, wind speed, humidity, plant type, (including leaf area and root zone) texture of surface soil, and availability of water.

Precipitation in excess of losses due to surface runoff and E-T will result in net infiltration or deep percolation to soils below the root zone. This net infiltration is considered comparable to the long-term leaching rate at land disposal facilities. Site specific facility conditions such as low permeable layers or drainage layers may cause the leaching rate to be less than net infiltration since these layers may divert percolating water from underlying waste.

2.1.2 Analysis Method

Quantitative estimates of leaching rates are typically calculated using the Hydrologic Evaluation of Landfill Performance (HELP) model or the Water Budget (WATBUG) model. The HELP model relies on the Penman technique to estimate net infiltration and was developed by EPA in 1980 (Perrier and Gibson, 1980) and most recently revised in 1984 (Schroeder, et al., 1984) specifically for hazardous waste landfills. The WATBUG model relies on the Thornthwaite method


20
25
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70
80
90

ADAPTED FROM:

LINSLEY AND FRANZINI, WATER RESOURCES ENGINEERING; McGRAW HILL, NEW YORK, 1979; P. 32

FIGURE 2-2
AVERAGE ANNUAL LAKE EVAPORATION (IN INCHES)

(Thornthwaite and Mather, 1957) of estimating net infiltration and has been used for landfill applications in automated form since 1980 (Mather, et al., 1980) and manual form since 1975 (Fenn, et al., 1975). The HELP model conducts the water balance computations on a daily time step, but relies on average monthly temperatures; and the WATBUG model relies on a monthly time step.

The HELP model was adapted from similar models developed by the US Department of Agriculture and incorporates analytical modules that account for drainage barrier layers that can be installed in cover or liner systems. The WATBUG, in the form presented by Mather, does not account for such drainage layers.

The HELP model is readily available through a National Technical Information Service (NTIS) time-share computer and includes the most recent 5 years of climatic data at more than 100 reporting stations. The WATBUG uses a 25-year average of climatic conditions and requires that precipitation data be entered into the computer for each station.

The HELP model was chosen to conduct this analysis of the leaching rate for the following reasons:

- the model is currently being validated and documented by the EPA for land disposal sites; whereas a comparable validation and documentation is not available for the WATBUG model;

- ease of access to the large number of reporting stations compared to manual entry for WATBUG;

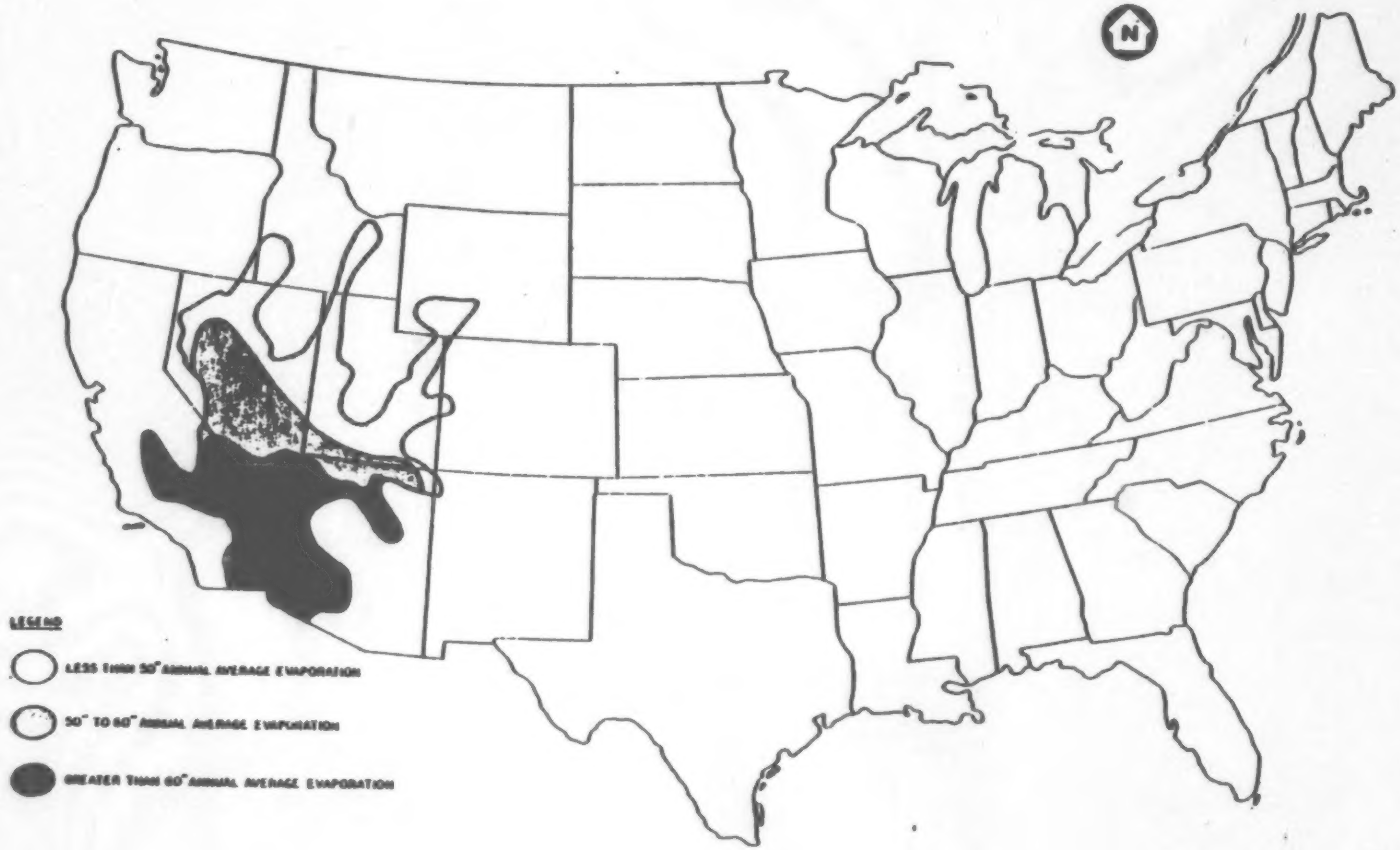
- 5 years of data was not considered to be an overly restrictive data base compared to 25 years (see Appendix A); and

- barrier and drainage layer performance is already incorporated into the HELP model.

2.2 Climatic Data Base

The precipitation data, Figure 2-1, and evaporation data, Figure 2-2, were used to identify ranges of conditions that may be encountered in the contiguous 48 states. These conditions are summarized in Figures 2-3 through 2-8. Six precipitation ranges were selected as representative of the U.S. and three E-T conditions were selected. A total of 18 climatic conditions were identified for developing the national leaching rate distributions. Greater definition of the distribution is possible by selecting a larger number of precipitation and/or evaporation conditions. If greater definition is desired, emphasis should be placed in areas of the country where precipitation is greater than E-T because these areas yield the larger leaching rates.

A reporting station of climatic data was selected in each of the 18 areas shown in Figures 2-3 through 2-8. Stations were selected from the more than 100 cities included in the HELP model data base. Cities selected are listed in Table 2-1. Since some areas selected are larger than others, it may be desirable to relate the estimated leaching rate to the percent of the total area of the contiguous 48 states.

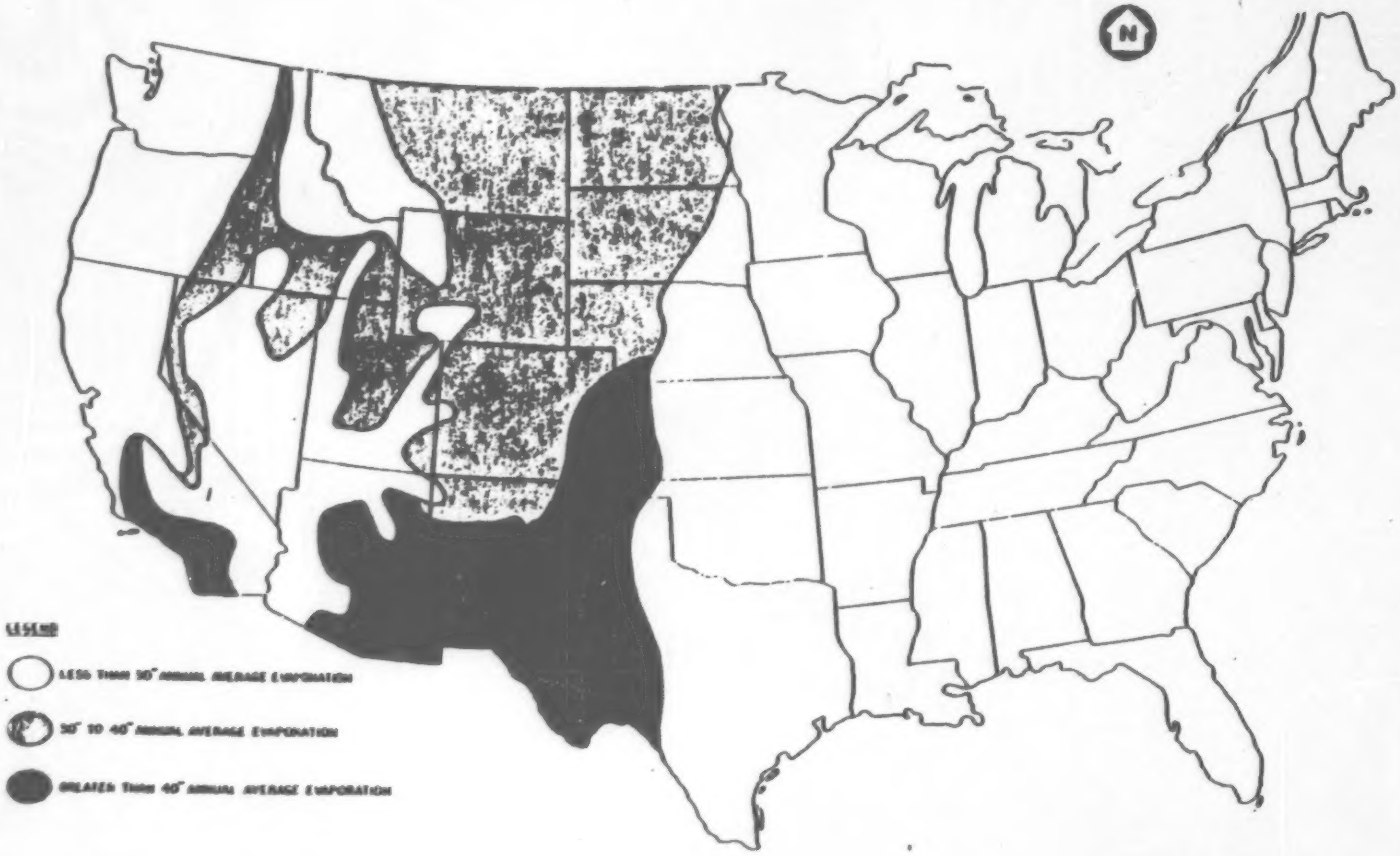

LEGEND
LESS THAN 50" ANNUAL AVERAGE EVAPORATION
50" TO 60" ANNUAL AVERAGE EVAPORATION
GREATER THAN 60" ANNUAL AVERAGE EVAPORATION

ADAPTED FROM:

LAKE EVAPORATION - LINSLEY AND FRANZINI, WATER RESOURCES ENGINEERING; McGRAW HILL, NEW YORK, 1979, P. 32

PRECIPITATION - LINSLEY, KOHLER, AND PAULHUS, HYDROLOGY FOR ENGINEERS, McGRAW HILL, NEW YORK, 1982, P. 78

FIGURE 2-3
LESS THAN 10" ANNUAL AVERAGE PRECIPITATION


N
LEGEND
LESS THAN 30" ANNUAL AVERAGE EVAPORATION
30" TO 40" ANNUAL AVERAGE EVAPORATION
GREATER THAN 40" ANNUAL AVERAGE EVAPORATION

ADAPTED FROM

LAKE EVAPORATION - LINSLEY AND FRANZINI, WATER RESOURCES ENGINEERING, McGRAW HILL, NEW YORK, 1979, P 32

PRECIPITATION - LINSLEY, KOHLER, AND PAULHUS, HYDROLOGY FOR ENGINEERS, McGRAW HILL, NEW YORK, 1982, P 38

FIGURE 2-4
10" TO 20" ANNUAL AVERAGE PRECIPITATION

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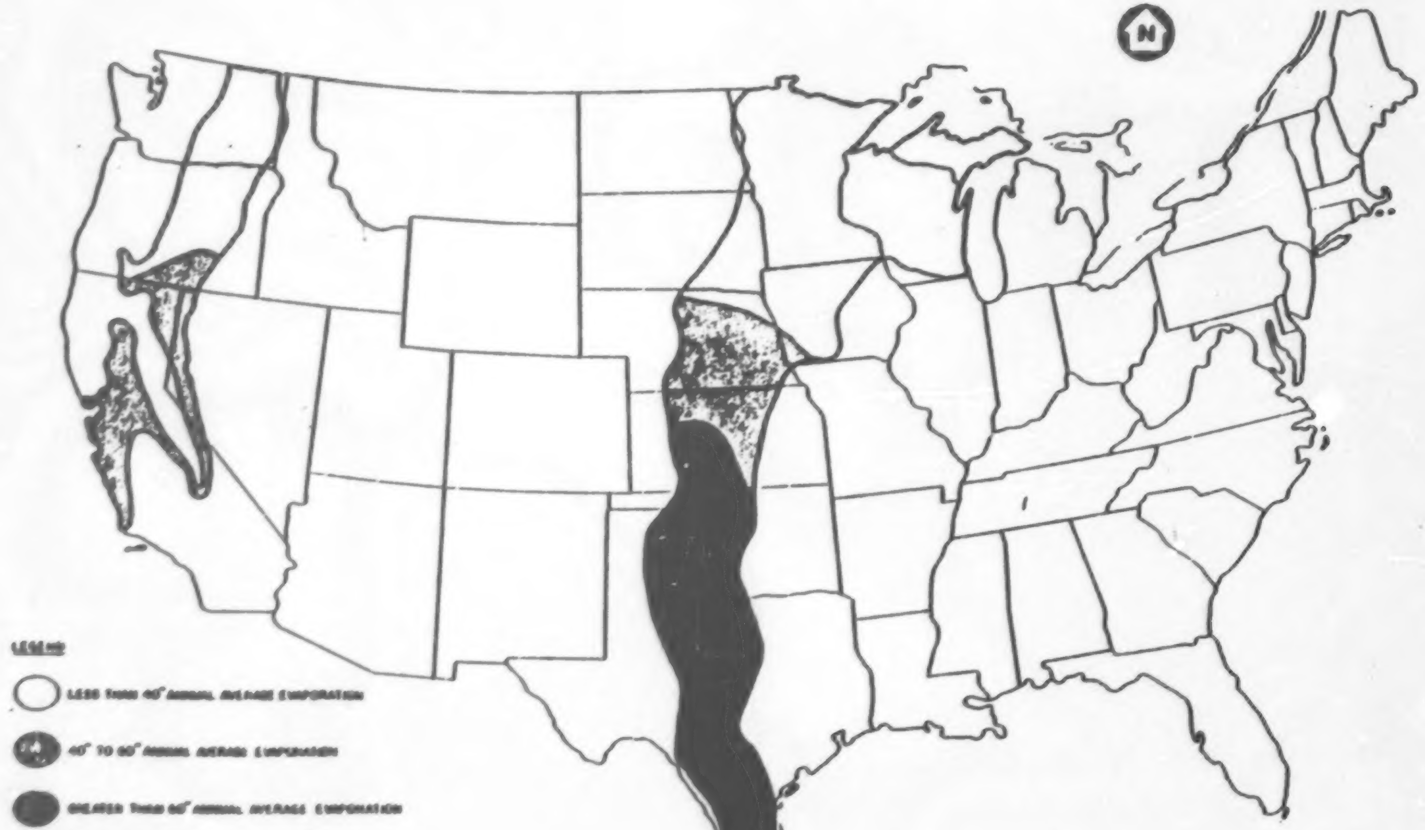


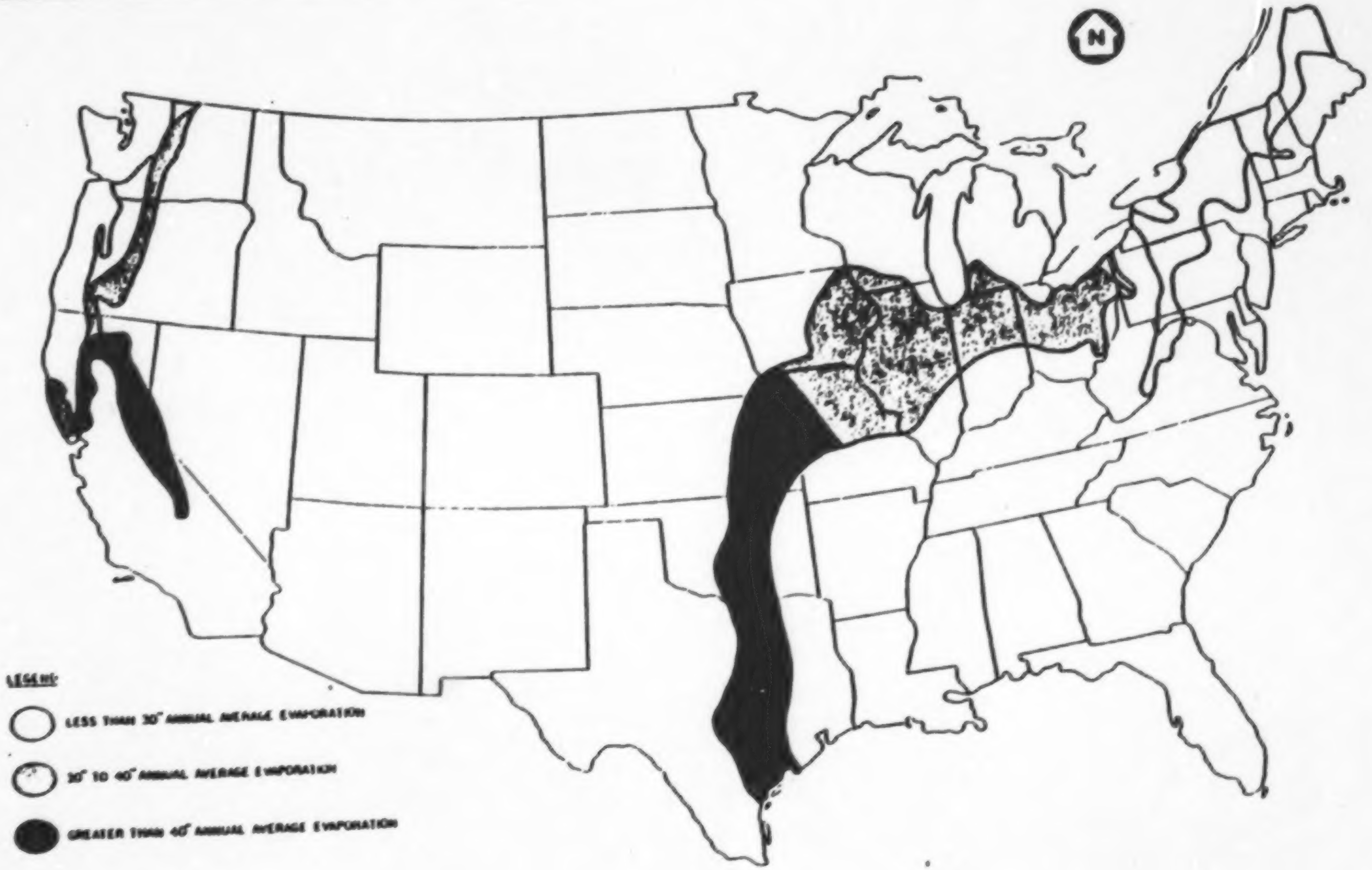
LEGEND
LESS THAN 40" ANNUAL AVERAGE EVAPORATION
40" TO 60" ANNUAL AVERAGE EVAPORATION
GREATER THAN 60" ANNUAL AVERAGE EVAPORATION
N

ADAPTED FROM

LAKE EVAPORATION - LINSLEY AND FRANZINI, WATER RESOURCES ENGINEERING, McGRAW HILL, NEW YORK, 1979, P. 32

PRECIPITATION - LINSLEY, KOHLER, AND PAULHUS, HYDROLOGY FOR ENGINEERS, McGRAW HILL, NEW YORK, 1982, P. 7b

FIGURE 2-5
20" TO 32" ANNUAL AVERAGE PRECIPITATION


N
LEGEND:
○ LESS THAN 30" ANNUAL AVERAGE EVAPORATION
◌ 30" TO 40" ANNUAL AVERAGE EVAPORATION
● GREATER THAN 40" ANNUAL AVERAGE EVAPORATION

ADAPTED FROM
LAKE EVAPORATION - LINSLEY AND FRANZINI, WATER RESOURCES ENGINEERING, McGRAW HILL, NEW YORK, 1979, P 32
PRECIPITATION - LINSLEY, KOHLER, AND PAULHUS, HYDROLOGY FOR ENGINEERS, McGRAW HILL, NEW YORK, 1982, P 78

FIGURE 2-6
32" TO 40" ANNUAL AVERAGE PRECIPITATION

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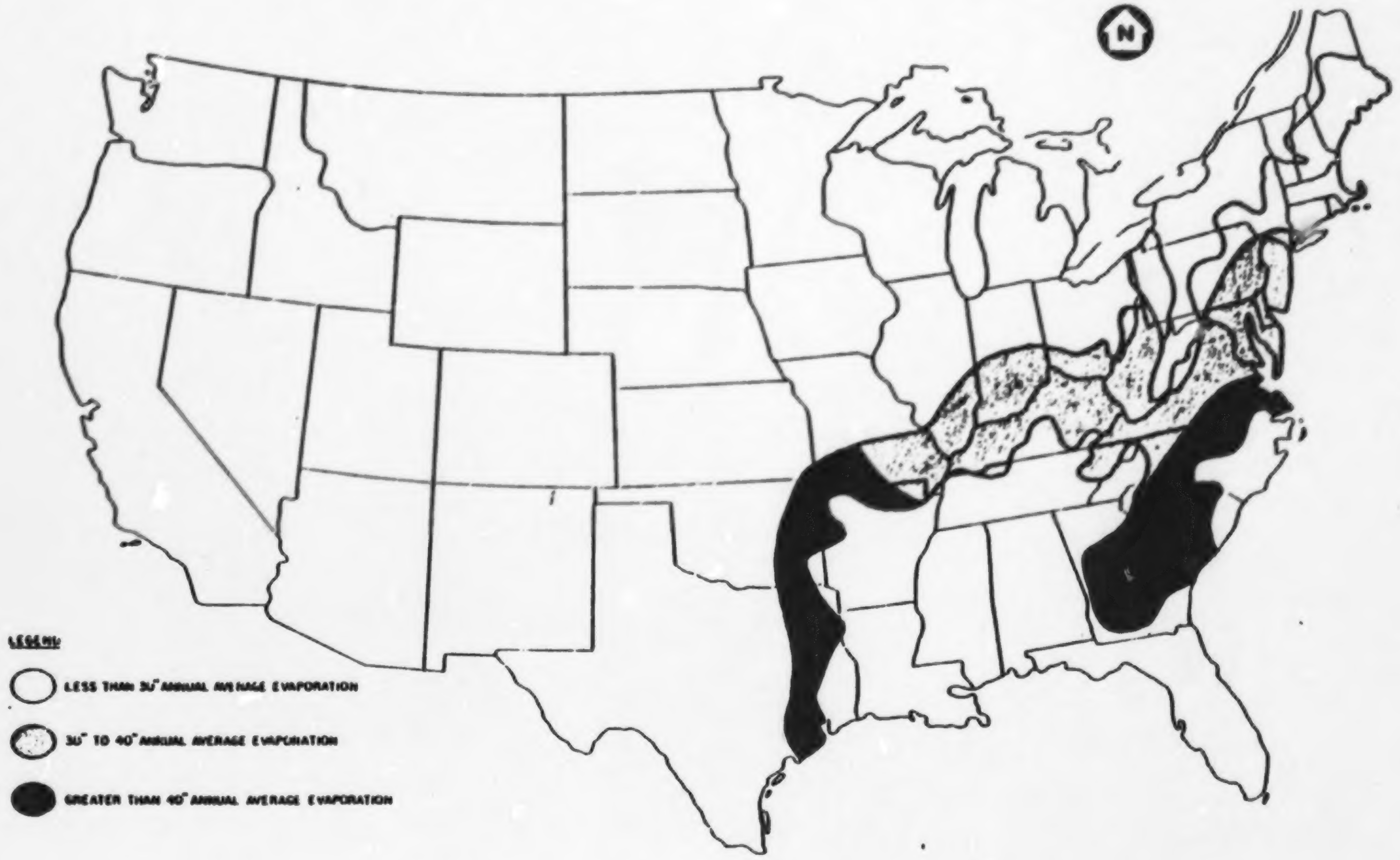
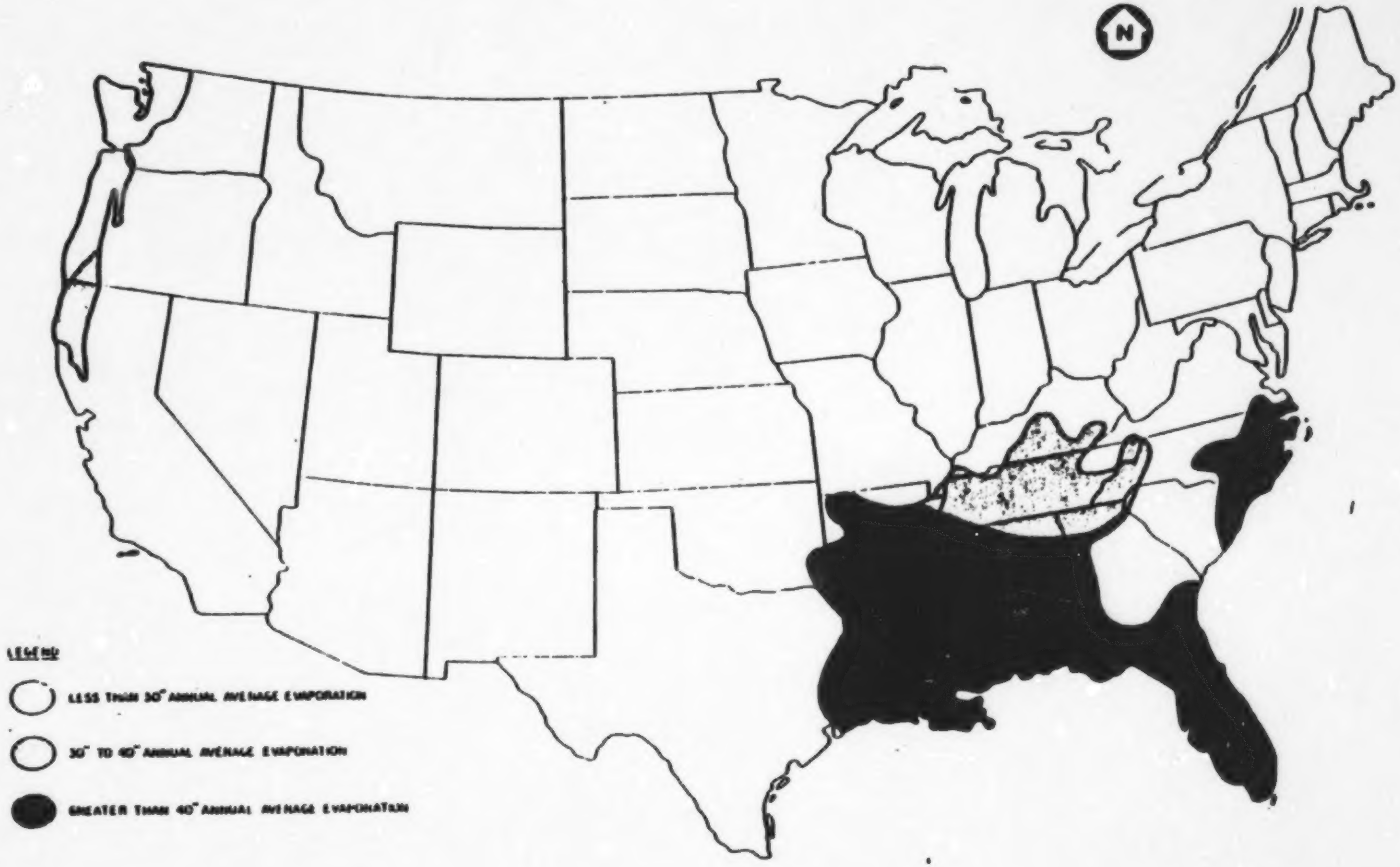

N
LEGEND:
LESS THAN 30" ANNUAL AVERAGE EVAPORATION
30" TO 40" ANNUAL AVERAGE EVAPORATION
GREATER THAN 40" ANNUAL AVERAGE EVAPORATION

ADAPTED FROM

LAKE EVAPORATION - LINSLEY AND FRANZINI, WATER RESOURCES ENGINEERING, McGRAW HILL, NEW YORK, 1979, P 32

PRECIPITATION - LINSLEY, KOHLER, AND PAULHUS, HYDROLOGY FOR ENGINEERS, McGRAW HILL, NEW YORK, 1982, P 70

FIGURE 2-7
40" TO 48" ANNUAL AVERAGE PRECIPITATION


N
LEGEND
LESS THAN 30" ANNUAL AVERAGE EVAPORATION
30" TO 40" ANNUAL AVERAGE EVAPORATION
GREATER THAN 40" ANNUAL AVERAGE EVAPORATION

ADAPTED FROM

LAKE EVAPORATION - LINSLEY AND FRANZINI, WATER RESOURCES ENGINEERING, McGRAW HILL, NEW YORK, 1979, P 32

PRECIPITATION - LINSLEY, KOHLER, AND PAULHUS, HYDROLOGY FOR ENGINEERS, McGRAW HILL, NEW YORK, 1982, P 78

FIGURE 2-8

GREATER THAN 48" ANNUAL AVERAGE PRECIPITATION

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TABLE 2-1

CITIES SELECTED FOR CLIMATIC DATA[a]

PRECIPITATION RANGE[b]	EVAPORATION POTENTIAL	CLIMATOLOGICAL CENTER	AVERAGE 5-YEAR PRECIPITATION[b]	PERCENT OF TOTAL AREA[c]
<10	Low	Pocatello, ID	9.8	3
	Medium	Cedar City, UT	9.8	2
	High	Las Vegas, NV	5.3	3
10-20	Low	Great Falls, MT	17.9	3
	Medium	Rapid City, SD	15.4	18
	High	Midland, TX	16.3	11
20-32	Low	St. Cloud, MN	25.8	9
	Medium	Grand Island, NE	22.2	4
	High	Oklahoma City, OK	30.4	5
32-40	Low	Montpelier, VT	34.5	3
	Medium	Cleveland, OH	36.7	5
	High	Columbia, MS	37.1	3
40-48	Low	Boston, MA	40.9	3
	Medium	Indianapolis, IN	40.3	7
	High	Charleston, SC	48.3	5
>48	Low	Astoria, OR	65.6	2
	Medium	Knoxville, TN	48.1	3
	High	Tallahassee, FL	68.4	11

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[a] Based on USEPA HELP model.
[b] Inches per year (assumes unit area).
[c] Percent of total area of contiguous 48 states.

2.3 Facility Conditions

The design conditions used in predicting the leaching rate are based on current state and federal regulations, and guidance criteria from EPA documents. The major design conditions considered in analyzing engineered controls include: cover and liner configuration (e.g., slope, soil types, barrier layer materials), type of vegetative cover and depth of root (evaporative) zone. The standard set conditions used in the analysis of Subtitle D and Subtitle C facilities are discussed below.

2.3.1 Subtitle D Facility. Subtitle D facilities are typically municipal solid waste landfills. These types of landfills are regulated by state agencies. These regulations include specific design requirements as well as site location, operating and other requirements. In addition, federal guidelines for Subtitle D facilities are found at 40 CFR 257. A review of state regulations concerning cover and liner requirements found the following:

1. 90 percent of the 50 states require a minimum of 2-feet of cover soil; and
2. 90 percent of the 50 states have no specific requirements for liner systems beneath Subtitle D facilities.

The type of soil selected for use in the cover must be able to support vegetation and to minimize infiltration. Soil textures, as classified by the U.S. Department of Agriculture (USDA), commonly used to meet this requirement include loamy sand, loam and clayey loam. A 24-inch thick loam soil placed on a slope of 2 to 5 percent will comply with the regulations found in over 90 percent of the 50 states and was selected for the standard conditions of this analysis. The type and condition of vegetative cover at the Subtitle D landfill influences the leaching rate by controlling infiltration rates, evapotranspiration and surface runoff. Landfill covers are usually seeded with a mixture of grass to control erosion. Because the cover soils required are expected to be conducive to grass growth, complete coverage or a good grass stand would be expected shortly (several years) after seeding the cover. The root zone of grass species can extend to 36 inches and more. However, the root zone is not expected to penetrate the waste layer, which is at a depth of 24 inches, due to unsuitable growing conditions in the waste layer. Waste material in sanitary landfills will decompose (e.g., production of acids, methane and carbon dioxide), creating an unsuitable growing condition which would inhibit the roots from penetrating below the cover soil layer.

Vegetative cover may progress to other species in the long-term, depending on the climatic conditions, indigenous species in the vicinity of the landfill, and growth conditions prevalent in the landfill cover. This long-term vegetative species progression was not considered since such a long-term vegetative species progression is highly sensitive to site-specific conditions, it may also be expected at Subtitle C facilities, and the greatest chemical flux at sanitary landfills occurs in the first several years after waste placement.

Based on the above information, the conditions used in analyzing long-term Subtitle D facility performance using the HELP model included:

- 2-feet of cover soil consisting of a loam texture and a good grass stand on a 2 to 5 percent slope;

- root zone of 24 inches; and

- no liner system beneath the site.

These conditions are depicted in Figure 2-9. A sensitivity analysis of soil texture and root zone depth is discussed in Section 3.0.

2.3.2 Subtitle C Facility. Subtitle C facilities are regulated by federal regulations for the disposal of hazardous wastes. Specifically, the regulations cited in the 40 CFR Parts 264 and 265 and requirements of the Amendments provide the framework for engineered controls. In addition, the EPA has issued guidance to owners and operators of land disposal facilities (Lutton, 1980; EPA, 1982; EPA, 1983; EPA, 1984; EPA, 1985). These engineered controls for disposal facilities include multi-layered cover/liner systems consisting of drainage layers, geomembrane barriers and soil barriers. Several cover/liner system configurations that will meet the regulations are depicted in Figure 2-10. The configurations include one cover system and three liner systems. The cover system consists of a 2-foot cover soil layer above a 1-foot drainage layer, a geomembrane liner bedded with filter fabric, followed by a 3-foot clay layer.

The liner systems shown on Figure 2-10 all include leachate collection and detection layers. The difference between the liner systems is the combination

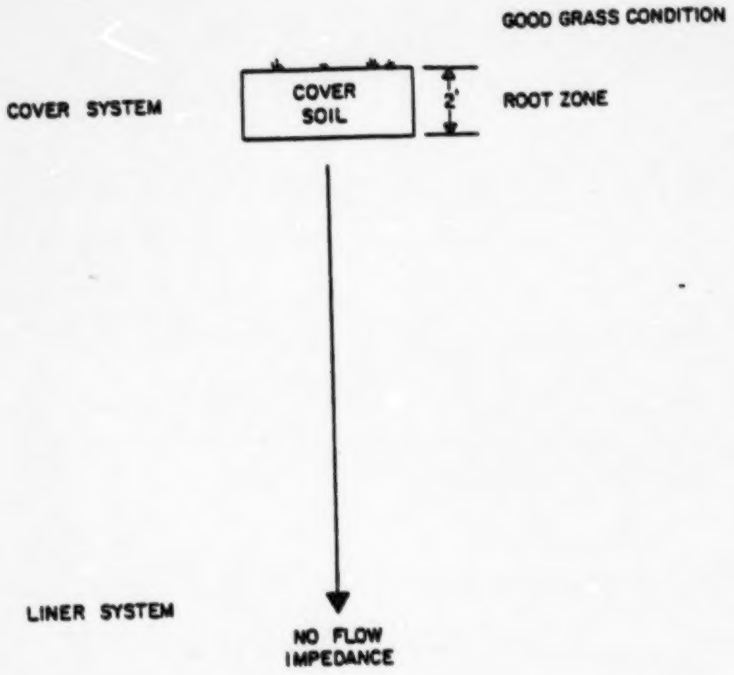
GOOD GRASS CONDITION
COVER SYSTEM
COVER SOIL
2'
ROOT ZONE
LINER SYSTEM
NO FLOW IMPEDANCE

FIGURE 2-9
SUBTITLE "D"
FACILITY CONDITIONS USED IN ESTIMATING LEACHING RATES

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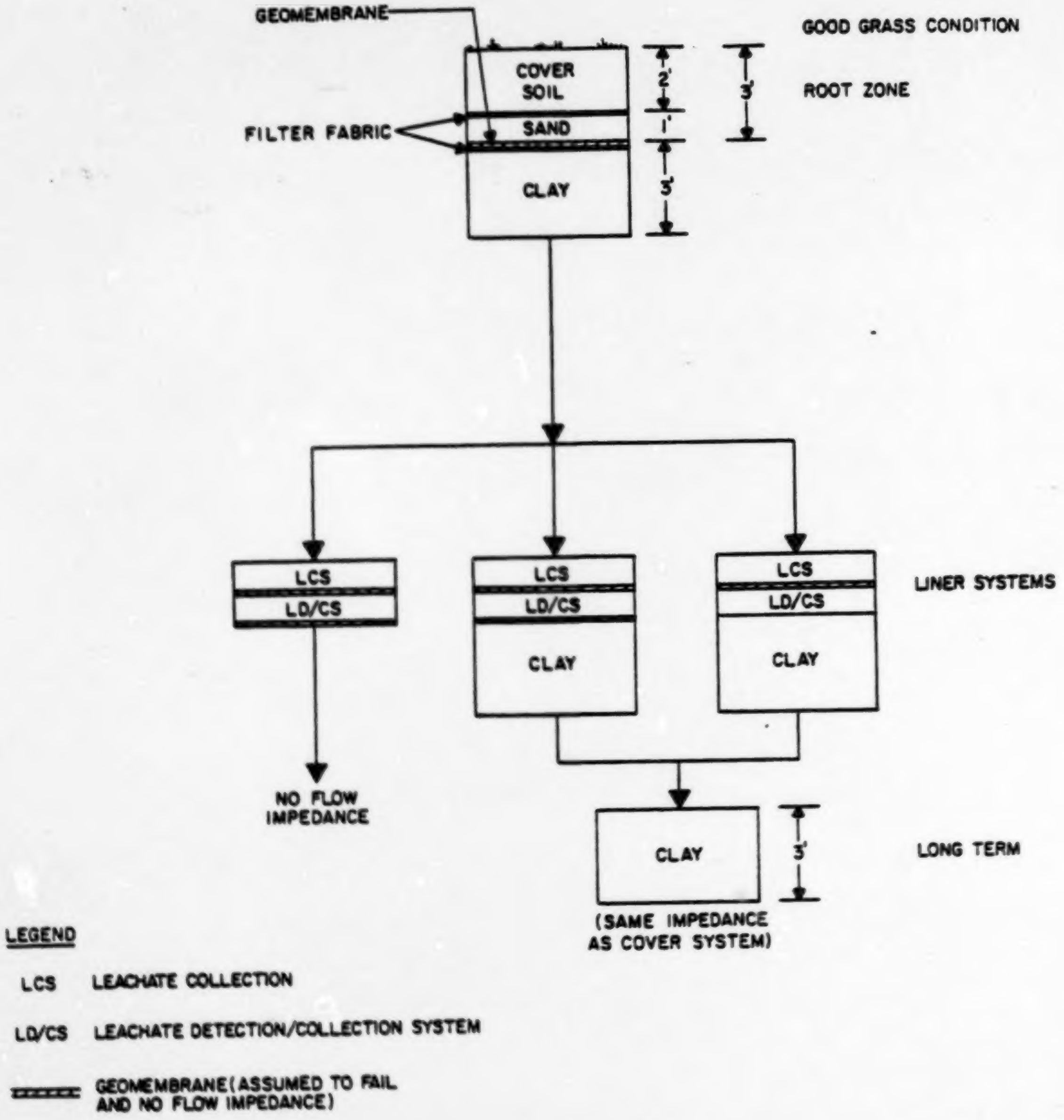
GEOMEMBRANE
GOOD GRASS CONDITION
COVER SOIL
2'
3'
ROOT ZONE
FILTER FABRIC
SAND
1'
CLAY
3'
LCS
LD/CS
LCS
LD/CS
CLAY
LCS
LD/CS
CLAY
LINER SYSTEMS
NO FLOW IMPEDANCE
CLAY
3'
LONG TERM
(SAME IMPEDANCE AS COVER SYSTEM)
LEGEND
LCS LEACHATE COLLECTION
LD/CS LEACHATE DETECTION/COLLECTION SYSTEM
GEOMEMBRANE (ASSUMED TO FAIL AND NO FLOW IMPEDANCE)

FIGURE 2-10

SUBTITLE "C"

FACILITY CONDITIONS USED IN ESTIMATING LEACHING RATES

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of barrier layers used. The combinations include the use of two geomembranes separated by a drain layer, a geomembrane separated from a clay layer, and a geomembrane separated from a geomembrane-clay composite layer.

Since the analysis of engineered controls is intended to evaluate long-term performance (e.g., several centuries), the leaching rate of configurations described above is expected to change.

The principal change affecting leaching rate is expected to be the degradation of the geomembranes to a point where they are no longer effective in controlling water movement. In addition, the leachate collection/detection systems that remove leachate from the facility are not expected to be operating over this period. The clay liners are expected to have greater hydraulic conductivity as a result of geologic change (e.g., weathering) and exposure to chemicals.

Practical experience with the performance of polymeric geomembranes as barriers to water flow is limited to a few decades. Use of geomembranes to contain mobile wastes in landfill environments is limited to less than 20 years. An assessment was made of the service life of geomembranes used to contain hazardous wastes at land disposal facilities (Lyman, et al., 1983) this assessment indicated there is limited data available on which to project long-term service life but containment may be expected over several decades and could possibly extend over 100 years. Since the long-term analysis of engineering controls considers performance over several centuries and the service life of geomembranes is estimated to be a fraction of this period, the effectiveness of geomembranes barriers to control leaching rates is expected to be equal to or less than clay barriers.

Clays are residual soils created through physical and chemical weathering of rocks and minerals such as feldspars in granite and pegmatites. The silicon-oxygen sheet structures of these minerals combine with aluminum, sodium, calcium, potassium and magnesium cations, some iron oxides and hydroxl molecules from water to form hydrous silicates -- mainly lcaolinite, illite and montmorillinite clays. Clays are relatively stable, although they exchange cations and dehydrate and hydrate to variable extents.

Clays are regionally distributed in the U.S. and are susceptible to specific geologic weathering processes. In general, the most important long-term weathering process of clay barriers at waste disposal facilities is the development of soil structure (fabric). Soil fabric may result from wetting and drying in response to percolating precipitation. Clay particles tend to flocculate and clump together in aggregates, or peds, when the clay dehydrates. The formation of peds is a slow gradual process that transforms the clay barrier into blocks of soil. These blocks of soil cause an increase in the hydraulic conductivity of the clay barrier. The extent of this increase depends on the extent of dehydration. Clay barriers in cover and liner systems are not as susceptible to formation of peds as similar clays at the ground surface since they are less susceptible to large fluctuations in moisture content caused by evapotranspiration of percolating water.

Naturally occurring clay soils near the ground surface can be considered representative of the extent of geologic weathering to which clay barriers in Subtitle C facilities will be exposed. A Soil Conservation Service survey of clay soils for states across the U.S. indicates hydraulic conductivity ranged from 1.4×10^{-4} to 4.3×10^{-8} cm/sec for soils at depth of 30 to 80 inches.

It is anticipated that natural clays with an in-situ hydraulic conductivity on the order of 10^{-6} cm/sec can be compacted to achieve the 10^{-7} cm/sec required by the Amendments. Therefore, the slower hydraulic gradient (4.3×10^{-8} cm/sec) is probably representative of the upper limit for hydraulic conductivity that may result from geologic weathering of clay barriers in engineered controls at Subtitle C facilities. An even slower hydraulic conductivity may be more typical of the long-term clay performance of clay barriers since some weathering processes, such as transport of fines by percolating water from the soils overlying the clay barrier tends to reduce hydraulic conductivity by plugging pores of the clay soil.

The use of clay soils as barrier layers in cover or liner systems is subject to both geologic weathering and alteration of the clay soil structure on exposure to chemicals. These alterations can lead to increased hydraulic conductivity.

Alteration of the clay soil structure may be caused by dissolving constituents of the clay mineral, including aluminum, iron and silica (Brown and Anderson, 1983). Changes in the colloidal characteristics of the clay mineral may cause flocculation and increased hydraulic conductivity. The extent of alteration is controlled by such factors as type of clay mineral, waste constituent, mixture of chemicals and concentration of chemicals. As these alterations progress increased flow of percolating liquids may cause piping. These alternations may cause the hydraulic conductivity of some clay soils to increase by a factor of 100 (Anderson, 1982). While much of the current knowledge of chemical interactions with clay is based on laboratory studies with concentrated chemicals, there is a potential for increased hydraulic conductivity to occur under field conditions. Additional information is needed to determine the increase in hydraulic conductivity caused by aqueous solutions of chemicals under field conditions. The increase, however, is not expected to be greater than the 100 fold increase observed for concentrated chemicals under laboratory conditions. A hydraulic conductivity range of 5×10^{-6} to 5×10^{-7} cm/sec appears to be reasonable to estimate long-term performance of clay barriers exposed to chemicals.

Based on the above information, the conditions used in analyzing long-term Subtitle C facility performance using the HELP model included:

- 2 feet of cover soil consisting of a loam texture and good grass stand;
- 1-foot drainage layer at a two percent slope to free drain at toe of slope;
- root zone of 36 inches; and
- 3-foot clay layer with a hydraulic conductivity of 1×10^{-6} cm/sec.

A bottom liner system was not included in the design because the clay layer in the bottom liner is subject to similar conditions as the clay layer in the cover system and is also exposed to chemicals leaching from the waste. Therefore, the hydraulic conductivity of the bottom clay liner is expected to be equal to or greater than the clay layer in the cover and is not expected to control the leaching rate.

A sensitivity analysis was conducted to determine the variation in estimated leaching rates by varying the cover soil texture, clay hydraulic conductivity and root zone depth. The results of this analysis is presented in Section 3.2.

3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 Leaching Rate Distributions

Leaching rates for Subtitle C (hazardous) and Subtitle D landfill facilities were estimated with the HELP model for conditions considered representative of long-term performance. Leaching rates were estimated for 18 climatic conditions encountered in the contiguous 48 states. A summary of leaching rates is provided in Table 3-1. This information is expressed as percent of area in the contiguous 48 states where leaching rates may be expected to equal or be less than the rate shown.

Estimates of leaching rates suggest the rates are not randomly distributed in the contiguous 48 states, but are highly dependent on the annual precipitation. Leachate was estimated for all chosen locations of Subtitle D facilities. These leaching rates ranged approximately 2 orders-of-magnitude (100 fold) from Pocatello, ID to Astoria, OR (35.9 inches per year), while precipitation ranged over one order-of-magnitude. Long-term leaching was not estimated to occur at Subtitle C facilities receiving less than 20 inches per year of precipitation (with one exception). Where leaching was estimated to occur at Subtitle C facilities, the rate was generally 2 to 3 times less than for Subtitle D facilities.

The distributions of leaching rates shown in Figure 3-1 indicate Subtitle C facilities are expected to leach at a rate less than for Subtitle D facilities.

TABLE 3-1

LEACHING RATES SUMMARY[a]

PRECIPITATION RANGE[b]	EVAPORATION POTENTIAL	LEACHING RATE[b] "C"	LEACHING RATE[b] "D"	CLIMATOLOGICAL CENTER	AVERAGE 5-YEAR PRECIPITATION[b]	PERCENT OF TOTAL AREA[c]
<10	Low	0.0	0.1	Pocatello, ID	9.8	3
	Medium	0.0	0.3	Cedar City, UT	9.8	2
	High	0.0	0.2	Las Vegas, NV	5.3	3
10-20	Low	0.0	0.8	Great Falls, MT	17.9	3
	Medium	0.0	0.6	Rapid City, SD	15.4	18
	High	0.4	1.2	Midland, TX	16.3	11
20-32	Low	0.3	1.5	St. Cloud, MN	25.8	9
	Medium	0.5	1.5	Grand Island, NE	22.2	4
	High	0.5	2.4	Oklahoma City, OK	30.4	5
32-40	Low	3.6	7.2	Montpelier, VT	34.5	3
	Medium	3.7	6.8	Cleveland, OH	36.7	5
	High	2.9	4.8	Columbia, MS	37.1	3
40-48	Low	7.0	12.1	Boston, MA	40.9	3
	Medium	3.3	6.8	Indianapolis, IN	40.3	7
	High	2.5	5.8	Charleston, SC	48.3	5
>48	Low	11.9	35.9	Astoria, OR	65.6	2
	Medium	7.1	12.2	Knoxville, TN	48.1	3
	High	6.9	12.1	Tallahassee, FL	68.4	11

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[a] Based on USEPA HELP model estimates. Estimates for Subtitle C facilities assume an evapotranspiration zone of 36 inches and 24 inches for Subtitle D facilities.

[b] Inches per year (assumes unit area).

[c] Percent of total area of contiguous 48 states.

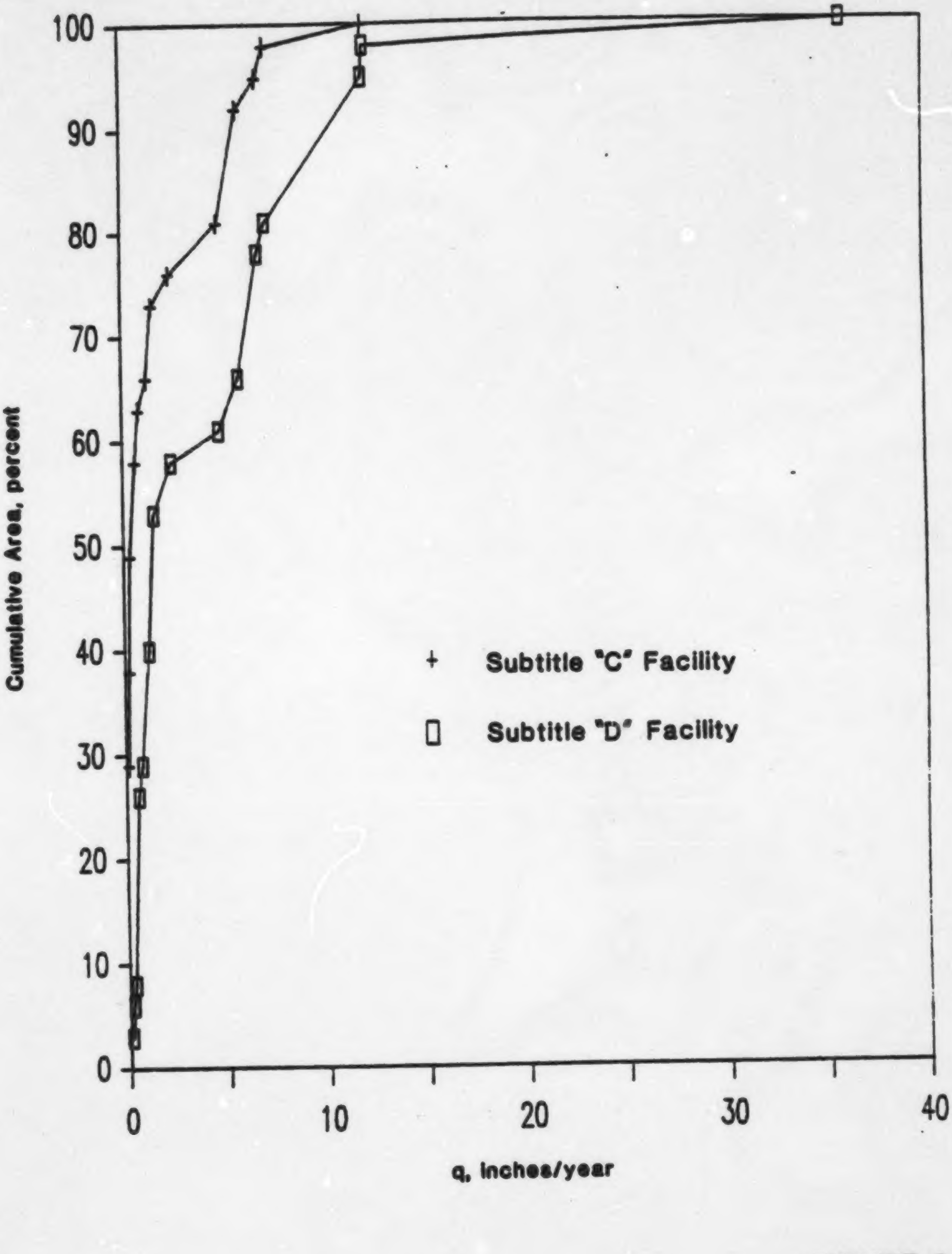

FIGURE 3-1

ESTIMATED DISTRIBUTION OF UNIT AREA LEACHING RATES FOR SUBTITLE C AND D FACILITIES

The distributions may be better defined if more climatological centers are evaluated (up to 100 reporting cities are included in the HELP data base), but the basic trends and differences are not expected to change dramatically.

3.2 Sensitivity Analysis

Since the leaching rates shown in Table 3-1 and Figure 3-1 were estimated for a standard set of conditions, an analysis was conducted to determine the effect on leaching rate over a range of conditions that may be encountered. This analysis was conducted using Indianapolis, IN. Other climatological centers would be expected to respond in a similar manner. Conditions that were varied included cover soil texture, hydraulic conductivity of the barrier layer and evapotranspiration zone.

Cover soil texture effect on estimated leaching rates was analyzed for loamy sand and clayey loam. These soils are considered reasonable substitutes for the loam soil that was used in the standard conditions. As may be expected, use of more permeable loamy sand in the cover to support vegetation was found to yield more leachate than loam. The leaching rate was almost doubled for the Subtitle C facilities while it was tripled for Subtitle D facilities. The leaching rate was less affected by use of clayey loam instead of loam (<10 percent at Subtitle C facilities and <20 percent at Subtitle D facilities). This suggests that the use of cover soils less permeable than loam will have a minor effect on the estimated leaching rate whereas the use of more permeable cover soils will increase leaching rates more at Subtitle D facilities than at Subtitle C facilities.

TABLE 3-2

SENSITIVITY ANALYSIS SUMMARY

CONDITION	LEACHING RATE[a]	
	q_C	q_D
Standard Conditions[b]	3.3	6.8
Soil Texture		
Loamy Sand	6.11	19.71
Clayey Loam	2.97	5.22
Hydraulic Conductivity, k		
5×10^{-6} cm/sec	4.3	-
5×10^{-7} cm/sec	2.2	-
Evapotranspiration (E-T) Zone		
Depth = half of standard condition	7.34	11.6

[a] inches per year (assumes unit area) for Indianapolis, IN location: q_C = Subtitle C facility
q_D = Subtitle D facility

[b] Standard Conditions included:

cover soil texture	loam
barrier layer hydraulic conductivity	10^{-6} cm/sec
evapotranspiration zone	36 inches for Subtitle C facility 24 inches for Subtitle D facility

3 Hydraulic conductivity in barrier layers in cover or liner systems was varied from 5×10^{-6} to 5×10^{-7} cm/sec to determine the effect on leaching rate from the standard condition of 10^{-6} cm/sec. Since Subtitle D facility cover systems were not assumed to provide such a barrier layer, the analysis was limited to Subtitle C facilities. The analysis indicated changes in leaching rates on the order of approximately 50 percent.

Reducing the depth of the zone where evapotranspiration may occur increased the Subtitle C leaching rate by a factor of almost 2.5, while the Subtitle D leaching rate increased by a factor of 1.7. This difference in effect on leaching rates caused by reducing the evapotranspiration zone suggests that the greater depth used for the Subtitle C facility (36 inches) provides more control over leaching rates than the shallower depth (24 inches) used for Subtitle D facilities.

Comparison of the relative importance of the conditions analyzed indicated the evapotranspiration depth is the most important condition for estimating Subtitle C leaching rates followed by use of more permeable soils for barriers and cover systems. The same two conditions, but in reverse order, were the most important in affecting Subtitle D leaching rates. In all cases, Subtitle D leaching rates were greater than for Subtitle C.

The sensitivity analysis was conducted over a reasonable range of long-term conditions. The estimated leaching rates over these ranges therefore provide a means of estimating the range of leaching rates that may be expected for these facilities under climatic conditions represented by Indianapolis, IN. Subtitle C facilities in Indianapolis may leach at a rate ranging from 2.2 to 7.34 inches per year, whereas, a Subtitle D leaching rate may range from 5.22 to 19.71 inches per year. The range of leaching rates may be greater if more than one standard condition is varied.

3.3 Application of Distributions

3.3.1 Use. Leaching rates and their frequency of occurrence in the contiguous 48 states were estimated for use in developing a generic procedure to classify wastes as hazardous and determine hazardous wastes to be banned from Subtitle C land disposal facilities. The leaching rates provide a means of estimating the chemical flux (mass rate of chemical release) from both Subtitle C and D facilities. The volumetric flux (volumetric rate of leachate production) identifies the transport rate which is leaching mobile chemicals out of the facility. When leaching rate is multiplied by concentration of chemicals in the leachate, then the chemical flux is described on a unit area basis. It is appropriate to express this flux on a unit area to maintain the generic application of the procedure.

The generic procedure is to be used to select chemical concentration criteria for use with a simple extraction procedure (e.g., Extraction Procedure III - organics). The EPA must ultimately select a specific leaching rate to determine the chemical concentration criterion that is protective of human health and the environment. Maximum protection is provided by selecting the greatest leaching rate.

Selection of an appropriate chemical concentration may be a complex task. An upper concentration limit may be identified as the solubility of the chemical in an aqueous solution. This assumes that wastes placed in the facility are not, or do not, contain free liquids and must dissolve into precipitation that percolates through the wastes. This approach to identifying a chemical concentration has several limitations:

- not all chemicals have solubility limits in water (i.e., some chemicals are miscible in water);
- solubility concentrations are rarely attained because of the inherent kinetics of the leaching process and chemical equilibria; and
- may far exceed actual leachate concentrations.

Alternatively, an appropriate concentration can be estimated by an iterative process to determine the concentration that, when released to an underlying groundwater system and transported downgradient to a receptor, does not cause adverse human health or environmental effects. This iterative process can be conducted after a specific leaching rate is selected or can be conducted on a mass flux basis (e.g., product of leaching rate and chemical concentration). The appropriate leaching rate and concentration that meets the chemical flux criterion can then be selected.

3.3.2 Limitations

Limitations of the leaching rate distributions and their use may be described as:

- analytical assumptions; and
- geographical distribution of leaching rates.

The analytical approach has several limitations that were described in Section 2. These limitations relate to the data base used to project long-term performance. Use of the HELP model is based on 5 consecutive years of climatic data. Although an assessment was made that suggested limited differences in average precipitation for the 5-year and 25-year periods, the significance of several years of abnormally high precipitation or permanent shift in climatic conditions has not been evaluated.

The conditions projected to prevail in the long-term are not based on an extensive long-term data base. Reasonable assumptions were made to identify a range of conditions that may prevail in the future. A particularly important assumption was that performance is controlled by natural activities and not by human disturbance of the low permeable barrier.

Geographical distribution of the estimated leaching rates presents a limitation to its use in the generic procedure. Low leaching rates prevail in certain areas of the nation and high leaching rates in other areas. If a leaching rate is selected in establishing criteria for specific chemicals, then two undesirable effects may occur:

- over-regulation of wastes in areas with low leaching rates; and
- under-regulation of wastes if the leaching rate is larger than the rate selected for the criterion.

Under-regulation of wastes can be avoided by using the maximum estimated leaching rate for selecting chemical concentration criteria. Both limitations can be avoided by establishing land disposal banning criteria expressed as a mass flux (e.g., the product of leaching rate and concentration). The owner/operator of a specific facility could readily identify if a waste with appropriate testing results (i.e., EP-III) is banned. This approach allows higher concentrations in areas with low leaching rates and requires low concentrations in areas with high rates. Using the mass flux rate approach, the rule or classification procedure becomes national in scope, avoids over- or under-regulation, protects human and the environment, and allows climatic conditions and costs to control where wastes are deposited in a protective manner.

3.3.3 Summary

The analysis of engineered controls for land disposal of wastes yielded distributions of leaching rates (Figure 3-1) for the contiguous 48 states. The Subtitle C distribution yielded estimated leaching rates that were always less (generally 1/2 to 1/3) than the Subtitle D leaching rates. The depth of the evaporative zone was found to be the most sensitive long-term site condition used to estimate leaching rates at Subtitle C facilities. Soil texture was found to be the most sensitive long-term site condition for Subtitle D facilities.

The distributions are useful in developing a generic procedure for classifying hazardous wastes and banning wastes from land disposal facilities. The EPA may use the distributions to develop chemical criteria in one of the following approaches:

- select a leaching rate and then determine an appropriate chemical concentration criterion; or
- determine an appropriate chemical mass flux rate from a facility by back-calculation from a health/environmental based criterion; and establish a mass flux criterion with regional maps of leaching rates for use by owners/operators of disposal facilities; or
- establish a concentration criterion using the maximum leaching rate and over-regulate wastes in low leaching rate areas; or
- establish a concentration criterion using a leaching rate that will under-regulate higher leaching rate areas and over-regulate lower leaching rate areas.

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APPENDIX A

COMPARISON OF 5 AND 30 YEAR PRECIPITATION DATA

APPENDIX A

COMPARISON OF 5-YEAR AND 30-YEAR PRECIPITATION DATA

Analysis of the long-term performance of engineered controls at waste disposal facilities relied on the 5-year precipitation data base used in the HELP model. The appropriateness of using a 5-year data base was assessed by comparing the 5 year average annual precipitation to an average from a longer period.

Average annual precipitation collected over a 23- to 30-year period for the climatological centers used in the analysis of engineering controls compiled from "Climates of the States" (NOAA, 1980). These data are presented in Table A-1 along with the 5-year annual average precipitation computed for the HELP model data base. Comparison of the two averages for each center showed differences in averages from less than 1 percent to 27 percent. The larger differences tend to occur in the low precipitation ranges. Two-thirds of the centers exhibited average annual precipitation differences of less than 5 percent. The 5-year HELP averages for those centers in the higher precipitation ranges (>32 inches per year) were generally greater than for the 30 year average. This general trend was reversed for the lower precipitation ranges. In addition, the larger differences (>5 percent) were generally because the HELP data base provided a larger average annual precipitation than the 30-year average.

Based on the above assessment of average annual precipitation, the following observations are made:

TABLE A-1

COMPARISON OF 5 AND 30 YEAR AVERAGE PRECIPITATION

PRECIPITATION[a] RANGE	EVAPORATION POTENTIAL	CLIMATOLOGICAL CENTER	AVERAGE PRECIPITATION[a] 5-YEAR[b]	AVERAGE PRECIPITATION[a] 30-YEAR[c]	PERCENT DIFFERENCE
<10	Low	Pocatello, ID	9.8	10.8	9
	Medium	Cedar City, UT	9.8	9.97[d]	1
	High	Las Vegas, NV	5.3	4.16	27
10-20	Low	Great Falls, MT	17.9	14.99	19
	Medium	Rapid City, SD	15.4	17.55	12
	High	Midland, TX	16.3	13.31	22
20-32	Low	St. Cloud, MN	25.8	26.84	3
	Medium	Grand Island, NE	22.2	23.41	5
	High	Oklahoma City, OK	30.4	31.73	4
32-40	Low	Montpelier, VT	34.5	33.23[e]	3
	Medium	Cleveland, OH	36.7	34.93	5
	High	Columbia, MS	37.1	37.39	0.7
40-48	Low	Boston, MA	40.9	41.50	1
	Medium	Indianapolis, IN	40.3	39.90	0.8
	High	Charleston, SC	48.3	48.73	0.8
>48	Low	Astoria, OR	65.6	66.34	1
	Medium	Knoxville, TN	48.1	46.18	4
	High	Tallahassee, FL	68.4	61.58	11

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[a] Inches per year (assumes unit area)
[b] Based on HELP model, May, 1985.
[c] Based on "Climates of the States".
[d] 24-year average.
[e] 23-year average.

- distribution of leaching rates estimated using the HELP model tend to over-estimate the long-term performance of land disposal facilities;

- the larger differences between the two precipitation averages are associated with the lower precipitation ranges (<20 inches per year) which were estimated to yield small leaching rates.

App. D of #7 (# 4) - App. [illegible] A)

#2
APP D
APP A

CONSULTING ENGINEERS

4756-02

January 10, 1986

Mr. James Bulman
U. S. Environmental Protection Agency
WH 562 B
401 M Street SW
Washington, DC 20460

Dear Mr. Bulman:

Subject: Reference Citations
Work Assignment No. 24
EPA Contract No. 68-01-7075

As you requested of Dirk Brunner, the reference citation on page 2-21 of the June 1985 report is enclosed. The reference is a compilation of 14 Soil Conservation Reports. The copies enclosed consist of the title page and pertinent pages within each document.

We apologize for the delay in submitting this information. If you have any questions do not hesitate to call Dirk Brunner or me.

Sincerely,

E. C. JORDAN CO.

Guy H. Cote Jr.

Guy H. Cote, Jr., P.E.
Environmental Engineer

GHC:ljs

Enclosures

CC: D. Brunner
M. Branscome
S. Albrecht

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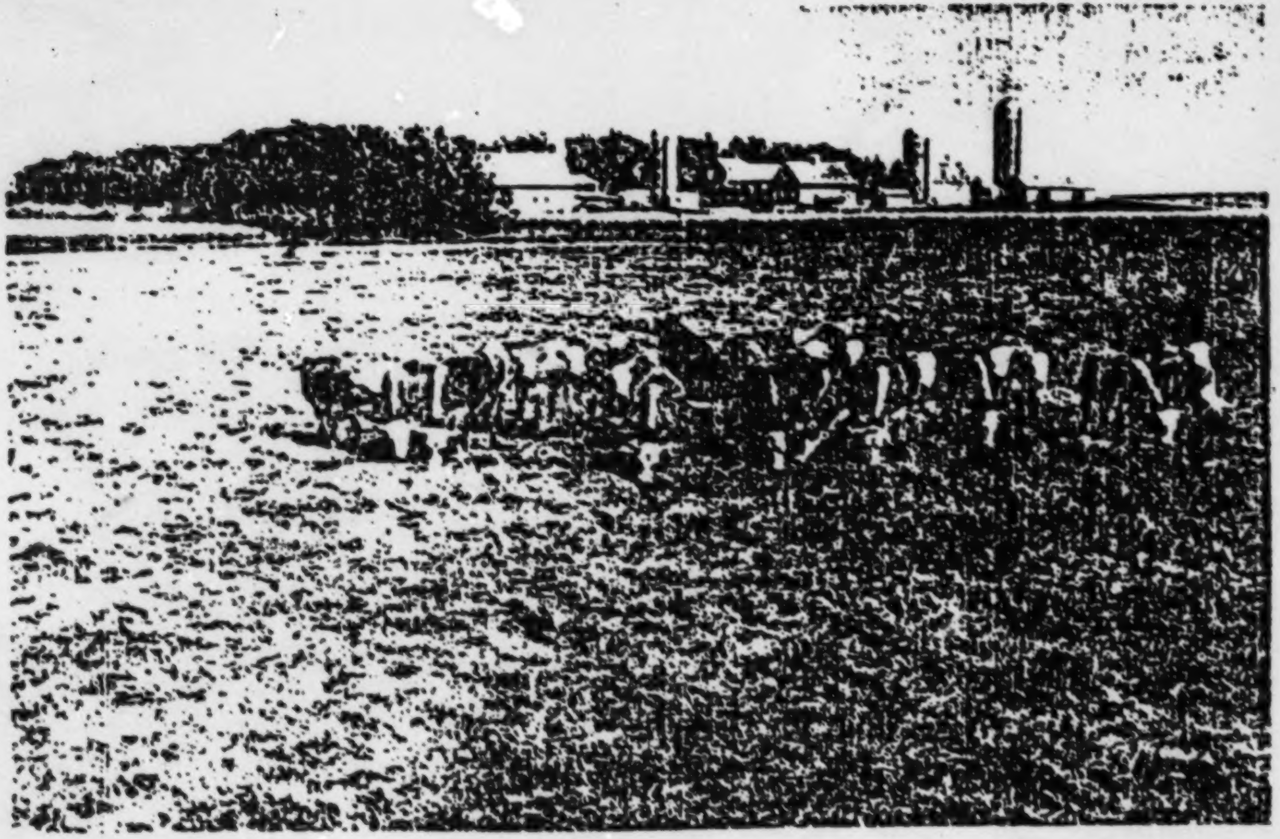
SOIL SURVEY OF

Lincoln County, South Dakota



United States Department of Agriculture
Soil Conservation Service
In cooperation with
South Dakota Agricultural Experiment Station

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2

SOIL SURVEY OF LINCOLN COUNTY, SOUTH DAKOTA

BY JAMES L. DRIESSEN, SOIL CONSERVATION SERVICE

SOILS SURVEYED BY JAMES L. DRIESSEN, GRAYSON E. MURPHY, AND W. D. WIESNER,
SOIL CONSERVATION SERVICE

UNITED STATES DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE, IN
COOPERATION WITH THE SOUTH DAKOTA AGRICULTURAL EXPERIMENT STATION

LINCOLN COUNTY is in the southeastern part of South Dakota (fig. 1). It has a total area of 368,640 acres. Canton, the county seat, is the largest town. Other towns and villages are Fairview, Harrisburg, Hudson, Lennox, Tea, and Worthing. A small part of Sioux Falls, the largest city in South Dakota, extends into the northern edge of the county.

Elevation ranges from less than 1,300 feet along the Big Sioux River to about 1,500 feet on uplands. Most of the county is nearly level to gently undulating, but relief is gently undulating to strongly sloping in the southeastern and northwestern parts. Hilly to steep areas are adjacent to the bottom lands of the Big Sioux River and also along some of the creeks. Much of the county is drained by the Big Sioux River and its tributaries. Long Creek and other tributaries of the Vermillion River drain the west-central and southwestern parts of the county.

General livestock farming is the main type of farming in the county, and it is the main source of income. About 82 percent of the county is cropped. Corn, oats, soybeans, and alfalfa are the main crops. Barley, flax, rye, wheat, and tame grasses are also grown. Beef cattle and swine are the main types of livestock.

How This Survey Was Made

Soil scientists made this survey to learn what kinds of soil are in Lincoln County, where they are located, and how they can be used. The soil scientists went into the county knowing they likely would find many soils they had already seen and perhaps some they had not. They observed the steepness, length, and shape of slopes; the size and nature of streams; the kinds of native plants or crops; the kinds of rock; and many facts about the soils. They dug many holes to expose soil profiles. A profile is the sequence of natural layers, or horizons, in a soil; it extends from the surface down into the parent material that has not been changed much by leaching or by the action of plant roots.

The soil scientists made comparisons among the profiles they studied, and they compared these profiles with those in counties nearby and in places more distant. They classified and named the soils according to nationwide, uniform procedures. The *soil series* and the *soil phase* are the categories of soil classification most used in a local survey.

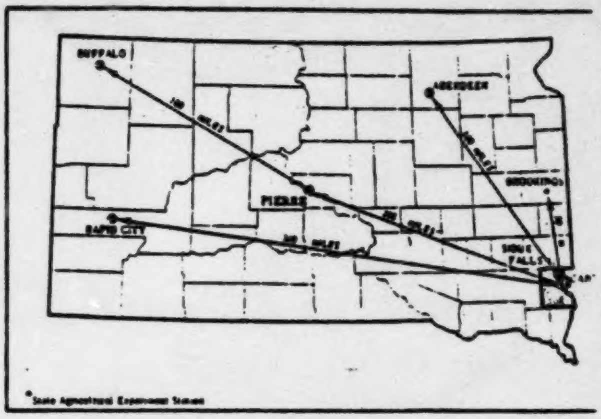

Figure 1.—Location of Lincoln County in South Dakota.

Soils that have profiles almost alike make up a s series. Except for different texture in the surface lay all the soils of one series have major horizons that a similar in thickness, arrangement, and other importa characteristics. Each soil series is named for a town other geographic feature near the place where a soil that series was first observed and mapped. Alcest and Worthing, for example, are the names of two s series. All the soils in the United States that have t same series name are essentially alike in those chara teristics that affect their behavior in the undisturbe landscape.

Soils of one series can differ in texture of the surface layer and in slope, stoniness, or some other characteristic that affects use of the soils by man. On th basis of such differences, a soil series is divided int phases. The name of a soil phase indicates a featur that affects management. For example, Dempster si loam, 0 to 2 percent slopes, is one of two phases withi the Dempster series.

After a guide for classifying and naming the soi had been worked out, the soil scientists drew the boun aries of the individual soils on aerial photograph These photographs show woodlands, buildings, fie borders, trees, and other details that help in drawin boundaries accurately. The soil map at the back of th publication was prepared from aerial photographs.

TABLE 4.—*Estimated soil properties*

Soil series and map symbols	Depth to seasonal high water table	Depth from surface	Dominant USDA texture	Classification		Percentage less than 3 inches passing sieve—			
				Unified	AASHO	No. 4 (4.7 mm)	No. 10 (2.0 mm)	No. 40 (0.42 mm)	No. 200 (0.074 mm)
	Ft	*In*							
Luton: Lu	[1]2–8	0–48	Silty clay	CH or MH	A-7	100	100	90–100	90–100
		48–60	Silty clay	CH or MH	A-7	100	100	90–100	85–95
Marsh: Mh. No valid estimates can be made.									
*Moody: MoA, MoB, MpB, MpC2. For Nora part of MpB and MpC2, see Nora series.	>5	0–10	Silty clay loam	CL	A-6 or A-7	100	100	95–100	85–100
		10–28	Silty clay loam	CL	A-6 or A-7	100	100	95–100	85–100
		28–60	Silt loam	ML or CL	A-6 or A-4	100	100	90–100	70–95
Nora Mapped only in complex with Crofton and Moody soils.	>10	0–7	Silty clay loam	CL	A-6 or A-7	100	100	95–100	80–95
		7–22	Silt loam	ML or CL	A-6 or A-7	100	100	90–100	70–90
		22–60	Silt loam	ML or CL	A-6 or A-4	100	100	90–100	70–90
Renner Mapped only in complex with Shindler soils.	>5	0–18	Loam	ML-CL or CL	A-6 or A-4	95–100	95–100	85–95	60–75
		18–29	Clay loam	CL	A-6 or A-7	95–100	95–100	85–95	70–80
		29–46	Clay loam	CL	A-6 or A-7	95–100	95–100	85–95	70–80
		46–60	Clay loam	CL	A-6 or A-7	95–100	95–100	85–95	70–80
Salmo: Sa	[1]0–2	0–50	Silty clay loam	CL or ML-CL	A-6 or A-7	100	100	90–100	70–90
		50–60	Silty clay loam	CL or ML-CL	A-6 or A-7	100	100	90–100	70–90
*Shindler: ShD, ShF, SkD2, SmF, StD. For Egan part of SkD2, see Egan series; for Renner part of SmF, see Renner series; for Talmo part of StD, see Talmo series.	>10	0–11	Clay loam	CL	A-6 or A-7	95–100	95–100	90–100	70–85
		11–60	Clay loam	CL	A-6 or A-7	95–100	95–100	80–100	60–85
*Steinauer: SuF For Shindler part, see Shindler series.	>10	0–24	Clay loam	CL	A-6 or A-7	95–100	95–100	90–100	70–85
		24–60	Clay loam	CL	A-6 or A-7	95–100	95–100	90–100	70–80
Talmo Mapped only in complex with Delmont and Shindler soils.	>10	0–8	Gravelly loam	ML or CL	A-4 or A-6	80–95	75–85	60–75	50–60
		8–60	Sand and gravel	GM, GC, SC, or SW-SM	A-1 or A-2	40–80	30–70	20–50	15–30
Tetonka: Te	2–8	0–19	Silty clay loam, silt loam.	ML-CL or CL	A-6 or A-7	100	100	90–100	85–100
		19–41	Silty clay	CH or MH	A-7	100	100	90–100	90–100
		41–60	Clay loam	CL	A-7 or A-6	95–100	90–100	80–95	60–90
Thurman: ThB, ThC	>5	0–12	Fine sandy loam	SM or ML	A-2 or A-4	100	100	70–85	30–55
		12–44	Loamy fine sand	SM	A-2	100	90–100	60–85	15–35
		44–60	Fine sand	SM	A-2	100	90–100	50–80	10–30
Viborg Mapped only in complex with Chancellor soils.	5–10	0–23	Silty clay loam	CL	A-6 or A-7	100	100	95–100	85–95
		23–34	Silty clay loam	CL	A-6 or A-7	100	100	95–100	85–95
		34–60	Clay loam	CL	A-6 or A-7	100	100	90–100	70–80
Wakonda Mapped only in complex with Chancellor soils.	3–5	0–10	Silt loam	ML or CL	A-6	100	100	90–100	85–100
		10–60	Silt loam, silty clay loam.	CL	A-6 or A-7	100	95–100	90–100	70–95

4

significant to engineering—Continued

Liquid limit	Plasticity index	Permeability	Available water capacity	Reaction	Salinity	Shrink-swell potential	Corrosivity	
							Uncoated steel	Concrete
Pct		*In per hour*	*In per in of soil*	*pH*	*Mmhos per cm*			
50–74	22–50	<0.6	0.10–0.14	6.6–7.8	<2	High	High	Low.
50–74	22–50	<0.6	0.08–0.12	7.4–8.4	2–4	High	High	Low.
26–50	11–33	0.6–2.0	0.19–0.22	6.1–7.3	<2	Moderate	Moderate	Low.
26–50	11–33	0.6–2.0	0.17–0.20	6.6–7.3	<2	Moderate	Moderate	Low.
25–40	5–22	0.6–2.0	0.17–0.20	7.4–8.4	<2	Low or moderate	Moderate	Low.
26–50	11–33	0.6–2.0	0.19–0.22	6.6–7.3	<2	Low or moderate	Moderate	Low.
26–50	11–33	0.6–2.0	0.17–0.20	6.6–7.8	<2	Low or moderate	Moderate	Low.
25–40	5–22	0.6–2.0	0.17–0.20	7.4–8.4	<2	Low or moderate	Moderate	Low.
25–38	5–19	0.6–2.0	0.18–0.20	6.1–6.6	<2	Low	Moderate	Low.
30–45	11–25	0.6–2.0	0.19–0.22	6.1–6.6	<2	Moderate	High	Low.
30–45	11–25	0.6–2.0	0.17–0.20	6.1–7.3	<2	Moderate	High	Low.
30–45	11–25	0.2–0.6	0.17–0.20	7.4–8.4	2–4	Moderate	High	Moderate.
30–50	11–25	0.2–0.6	0.16–0.19	7.4–8.4	4–12	Moderate	High	High.
30–50	11–25	0.2–0.6	0.14–0.17	7.4–8.4	4–12	Moderate	High	High.
25–50	10–25	0.6–2.0	0.19–0.22	6.6–7.8	<2	Moderate	Moderate	Moderate.
25–50	10–25	0.2–0.6	0.17–0.20	7.4–8.4	2–4	Moderate	Moderate or high.	Moderate.
25–50	10–25	0.6–2.0	0.17–0.20	7.4–8.4	2–4	Moderate	Moderate	Moderate.
25–50	10–25	0.2–0.6	0.17–0.20	7.4–8.4	2–4	Moderate	Moderate or high.	Moderate.
15–38	5–15	0.6–2.0	0.11–0.15	6.6–8.4	<2	Low	Moderate	Low.
<20	NP–10	6.0–20.0	0.03–0.06	7.4–8.4	<2	Low	Moderate	Low.
26–40	7–20	0.6–2.0	0.19–0.22	6.6–7.3	<2	Moderate	Moderate	Moderate.
50–74	20–45	<0.06	0.10–0.14	6.6–7.8	<2	High	High	Moderate.
30–50	11–25	0.06–0.2	0.14–0.17	7.9–8.4	2–4	High	High	Moderate.
10–28	NP–10	2.0–6.0	0.14–0.17	6.6–7.3	<2	Low	Low	Low.
<20	NP–10	6.0–20.0	0.08–0.10	6.6–7.8	<2	Low	Low	Low.
<20	NP–10	6.0–20.0	0.06–0.08	7.4–8.4	<2	Low	Low	Low.
30–50	11–33	0.6–2.0	0.19–0.22	6.1–7.3	<2	Moderate	High	Low.
30–50	11–33	0.6–2.0	0.17–0.20	6.6–8.4	<2	Moderate	High	Low.
25–50	11–35	0.2–0.6	0.17–0.20	7.4–8.4	2–4	Moderate	High	Moderate.
25–40	11–22	0.6–2.0	0.19–0.22	7.4–8.4	2–4	Moderate	High	Moderate.
26–50	11–25	0.6–2.0	0.14–0.17	7.9–8.4	4–10	Moderate	High	Moderate.

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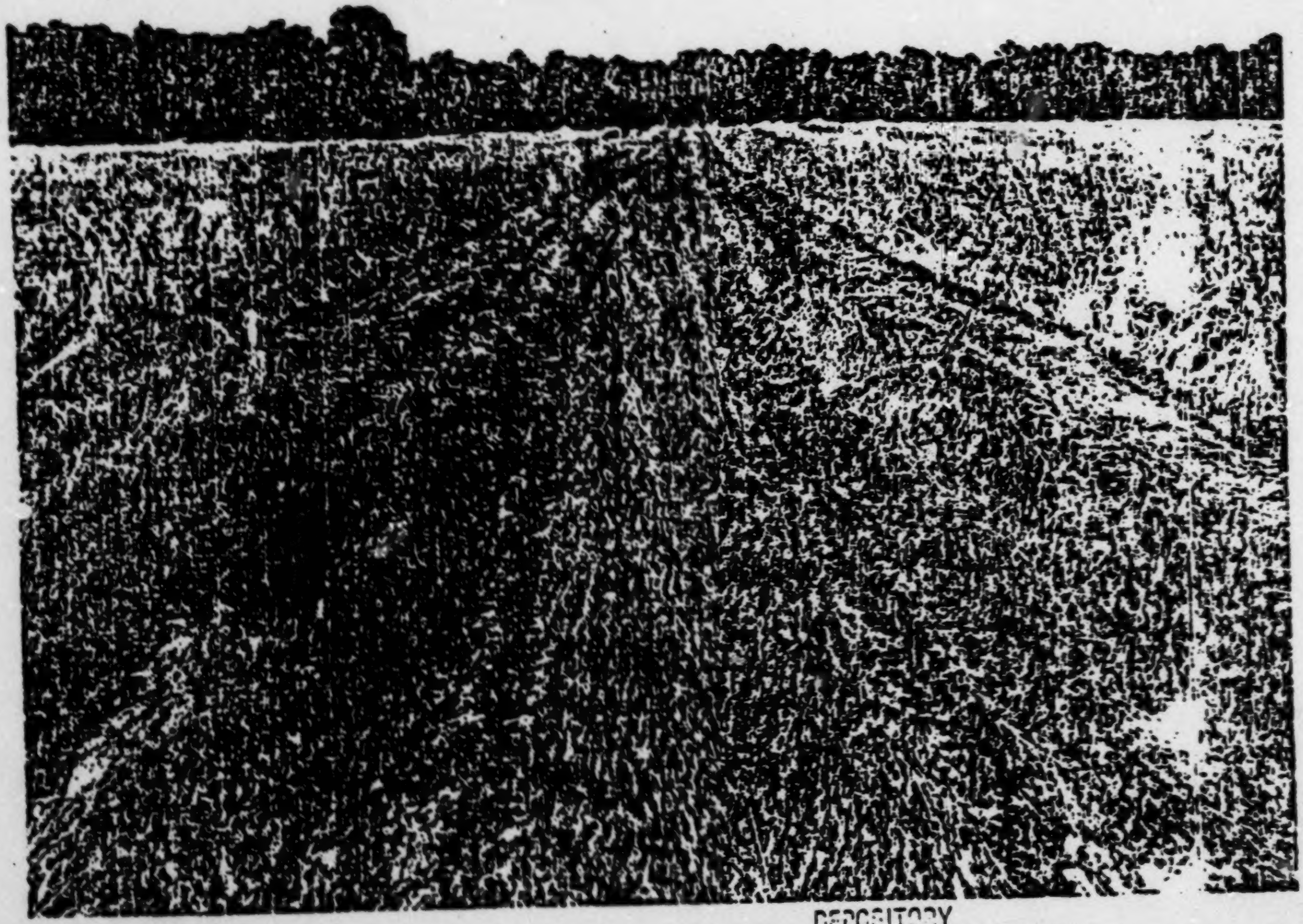
Department of Agriculture

Soil Conservation Service

In cooperation with
South Carolina Agricultural
Experiment Station and
South Carolina
Land Resources
Conservation Commission

Soil Survey of Aiken County Area South Carolina



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Soil Survey of
Aiken County Area, South Carolina

By Vergil A. Rogers, Soil Conservation Service

Soils surveyed by Vergil A. Rogers, G. E. Hardee, D. J. DeFrancesco,
and L. L. Brown, Soil Conservation Service

United States Department of Agriculture, Soil Conservation Service
In cooperation with South Carolina Agricultural Experiment Station
and South Carolina Land Resources Conservation Commission

AIKEN COUNTY AREA is located about midway between the mountains and the coast. On the west, Aiken County is separated from Georgia by the Savannah River. On the north it is bounded by Edgefield and Saluda Counties; on the east it is separated from Lexington County by Chinquapin Creek and North Fork Edisto River; and on the southeast it is bounded by Barnwell and Orangeburg Counties.

Aiken County takes in about 704,000 acres, but about 73,000 acres in the southern part of the county is part of the Savannah River Plant of the Department of Energy and is not included in this survey.

General Nature of the Survey Area

Three major land resource areas are represented in the county: the Carolina and Georgia Sand Hills, Southern Coastal Plain, and Southern Piedmont areas (*3*). For conciseness, they are referred to hereafter as the Sand Hills, Coastal Plain, and Piedmont.

Aiken County lies mainly within the Sand Hills belt, which includes nearly 80 percent of the survey area. The soils are dominantly gently sloping to moderately steep and well drained or excessively drained. They commonly have moderately thick or thick sandy material over a loamy subsoil, or they are sandy throughout. Some soils have a subsoil that is dense and brittle in part.

About 15 percent of the survey area is in the Coastal Plain area. The soils are dominantly nearly level to sloping and well drained. Most of the soils are sandy over a loamy or clayey subsoil.

About 1 percent of the survey area is in the Piedmont area. The soils are dominantly sloping to very steep. They have a loamy surface layer over a clayey subsoil.

Climate

Prepared by the National Climatic Center, Asheville, North Carolina.

Table 1 gives data on temperature and precipitation for the survey area as recorded at Aiken in the period 1951 to 1973. Table 2 shows probable dates of the first freeze in fall and the last freeze in spring. Table 3 provides data on length of the growing season.

In winter the average temperature is 48 degrees F, and the average daily minimum temperature is 37 degrees. The lowest temperature on record, which occurred at Aiken on January 10, 1970, is 4 degrees. In summer the average temperature is 79 degrees, and the average daily maximum temperature is 90 degrees. The highest recorded temperature, which occurred at Aiken on June 27, 1954, is 108 degrees.

Growing degree days are shown in table 1. They are equivalent to "heat units." During the month, growing degree days accumulate by the amount that the averag temperature each day exceeds a base temperature (50 degrees F). The normal monthly accumulation is used t schedule single or successive plantings between the las freeze in spring and the first freeze in fall.

The total annual precipitation is 48 inches. Of this, 26 inches, or 55 percent, usually falls in April through September. The growing season for most crops falls within this period. In 2 years out of 10, the rainfall in Ap through September is less than 21 inches. The heavies 1-day rainfall during the period of record was 9.68 inche

TABLE 15.--PHYSICAL AND CHEMICAL PROPERTIES OF THE SOILS

e symbol < means less than; > means more than. Entries under "Erosion factors--T" apply to the entire profile. Entries under "Wind erodibility group" and "Organic matter" apply only to the surface layer. Absence of an entry indicates that data were not available or were not estimated]

Map symbol and soil name	Depth	Clay	Moist bulk density	Permeability	Available water capacity	Soil reaction	Shrink-swell potential	Erosion factors		Wind erodibility group	Organic matter
								K	T		
	In	Pct	G/cm^3	In/hr	In/in	pH					Pct
B---------------- Ailey	0-23 23-30 30-72	3-8 14-20 18-35	--- --- ---	6.0-20 0.6-2.0 0.06-0.2	0.03-0.05 0.09-0.12 0.06-0.10	4.5-6.5 4.5-5.5 4.5-5.5	Low Low Low	0.10 0.24 0.17	4	---	<1
A---------------- ngie	0-11 11-74	4-14 35-60	1.35-1.65 1.20-1.60	0.6-6.0 0.06-0.2	0.10-0.15 0.12-0.18	4.5-6.5 3.6-5.5	Low High	0.32 0.32	5	---	.5-2
---------------- ayboro	0-8 8-65	10-35 35-65	1.30-1.50 1.20-1.40	0.6-2.0 0.06-0.2	0.15-0.20 0.14-0.18	4.5-5.5 4.5-5.5	Low Moderate	0.17 0.32	---	---	4-15
---------------- ethera	0-5 5-64	27-35 35-50	1.20-1.50 1.30-1.50	0.6-2.0 0.06-0.6	0.11-0.16 0.14-0.18	3.6-6.0 3.6-6.0	Moderate Moderate	0.28 0.32	5	6	1-6
---------------- ibb	0-7 7-60	2-18 2-18	--- ---	0.6-2.0 0.6-2.0	0.12-0.18 0.12-0.20	4.5-5.5 4.5-5.5	Low Low	0.20 0.37	5	---	.5-2
---------------- ewacla	0-10 10-65	10-27 18-35	1.30-1.60 1.30-1.60	0.6-2.0 0.6-2.0	0.15-0.24 0.12-0.20	4.5-6.5 4.5-6.5	Low Low	0.28 0.28	5	---	1-4
---------------- sher	0-6 6-60	--- ---	--- ---	2.0-6.0 ---	0.20-0.25 ---	3.6-4.4 ---	Low ---	--- ---	---	---	---
, DoB, DoC---- than	0-11 11-31 31-65	5-15 18-35 18-40	--- --- ---	2.0-6.0 0.6-2.0 0.2-0.6	0.06-0.10 0.12-0.16 0.08-0.12	4.5-5.5 4.5-5.5 4.5-5.5	Very low Low Low	0.15 0.28 0.28	5	---	<.5
---------------- nola	0-15 15-30 30-55 55-70	3-11 18-35 18-45 3-17	1.45-1.70 1.35-1.65 1.30-1.60 1.35-1.65	2.0-6.0 0.6-2.0 0.6-2.0 2.0-6.0	0.06-0.11 0.12-0.17 0.12-0.16 0.10-0.14	4.5-5.5 4.5-5.5 4.5-5.5 4.5-5.5	Low Low Low Low	0.17 0.28 0.32 0.24	5	---	.5-2
, FaB, FaC---- ceville	0-6 6-75	5-20 35-55	--- ---	6.0-20 0.6-2.0	0.06-0.09 0.12-0.18	4.5-5.5 4.5-6.0	Low Low	0.28 0.37	5	---	.5-2
---------------- xworth	0-47 47-80	2-8 2-6	1.35-1.55 1.40-1.55	>20 >20	0.05-0.10 0.03-0.08	4.5-6.0 4.5-6.0	Low Low	0.10 0.17	5	2	>1
, FuB, FuC---- quay	0-26 26-35 35-70	1-7 10-35 20-35	1.60-1.70 1.40-1.60 1.40-1.60	>6.0 0.6-2.0 0.06-0.2	0.03-0.07 0.12-0.15 0.10-0.13	4.5-6.0 4.5-6.0 4.5-6.0	Low Low Low	0.10 0.20 0.20	5	---	.5-2
, GrB, GrC---- eenville	0-12 12-60	5-20 35-55	1.30-1.65 1.35-1.55	0.6-6.0 0.6-2.0	0.07-0.14 0.14-0.18	4.5-6.0 4.5-6.0	Low Low	0.24 0.17	5	---	.5-1
---------------- dy	0-3 3-26 26-54 54-60	5-27 35-60 15-40 ---	1.30-1.50 1.20-1.50 1.30-1.50 ---	0.6-2.0 0.6-2.0 0.6-2.0 ---	0.14-0.20 0.10-0.19 0.12-0.18 ---	5.1-6.5 5.1-6.5 5.1-6.5 ---	Low Moderate Low ---	0.37 0.32 0.23 ---	3	5	.5-2
, HwE---------- wassee	0-4 4-45 45-65	7-20 35-60 7-35	1.45-1.65 1.30-1.45 1.45-1.65	0.6-2.0 0.6-2.0 0.6-2.0	0.10-0.14 0.12-0.15 0.10-0.14	4.5-6.5 4.5-6.5 4.5-6.5	Low Low Low	0.23 0.28 0.28	5	---	.5-2
---------------- nston	0-19 19-34 34-60	7-18 2-12 5-20	1.25-1.45 1.55-1.65 1.45-1.65	2.0-6.0 6.0-20 6.0-20	0.20-0.26 0.02-0.07 0.06-0.12	4.5-5.5 4.5-5.5 4.5-5.5	Low Low Low	0.17 0.17 0.17	5	---	8-18
LaD, LaE---- eland	0-66 66-80	2-8 1-6	1.35-1.65 1.50-1.60	6.0-20 6.0-20	0.05-0.09 0.02-0.08	4.5-6.0 4.5-6.0	Low Low	0.10 0.10	5	2	>1
LuB---------- y	0-26 26-31 31-70	1-12 10-30 20-35	--- --- ---	6.0-20 2.0-6.0 0.6-2.0	0.06-0.10 0.10-0.12 0.12-0.14	5.1-5.5 4.5-5.5 4.5-5.5	Low Low Low	0.15 0.24 0.28	5	---	.5-1

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TABLE 15.--PHYSICAL AND CHEMICAL PROPERTIES OF THE SOILS--Continued

Map symbol and soil name	Depth	Clay	Moist bulk density	Permeability	Available water capacity	Soil reaction	Shrink-swell potential	Erosion factors		Wind erodi-bility group	Organic matter
								K	T		
	In	Pct	G/cm^3	In/hr	In/in	pH					Pct
MaA, MaB---------- Marlboro	0-7 7-70	2-10 35-65	1.40-1.70 1.20-1.50	6.0-20 0.6-2.0	0.06-0.09 0.14-0.18	5.1-6.5 4.5-6.0	Low------------ Low------------	0.15 0.20	5	2	.5-2
Oc---------------- Ochlockonee	0-6 6-38 38-63	3-18 8-18 3-18	--- --- ---	2.0-6.0 0.6-2.0 2.0-6.0	0.07-0.14 0.10-0.20 0.06-0.12	4.5-5.5 4.5-5.5 4.5-5.5	Low------------ Low------------ Low------------	0.20 0.20 0.17	5	---	.5-2
Od---------------- Ocilla Variant	0-24 24-52 52-65	4-10 15-35 35-70	1.30-1.65 1.20-1.45 1.25-1.50	2.0-20 0.6-2.0 0.06-0.2	0.05-0.08 0.10-0.13 0.12-0.16	4.5-6.0 4.5-5.5 4.5-5.5	Low------------ Low------------ Moderate------	0.15 0.17 0.32	5	---	1-2
Og---------------- Ogeechee	0-15 15-45 45-65	5-10 20-35 15-30	1.30-1.60 1.30-1.50 1.30-1.60	0.6-2.0 0.2-0.6 0.6-2.0	0.10-0.14 0.08-0.14 0.10-0.14	4.5-5.5 4.5-5.5 4.5-5.5	Low------------ Low------------ Low------------	0.10 0.15 0.15	5	---	1-2
OrA, OrB, OrC---- Orangeburg	0-6 6-24 24-60	4-10 18-35 20-45	--- --- ---	2.0-6.0 0.6-2.0 0.6-2.0	0.06-0.09 0.11-0.14 0.11-0.14	4.5-6.0 4.5-5.5 4.5-5.5	Low------------ Low------------ Low------------	0.10 0.24 0.24	5	---	.5-1
PaB, PaD, PaE---- Pacolet	0-4 4-24 24-38 38-60	8-20 35-65 15-30 10-25	1.00-1.50 1.30-1.50 1.20-1.50 1.20-1.50	2.0-6.0 0.6-2.0 0.6-2.0 0.6-2.0	0.08-0.12 0.12-0.15 0.08-0.15 0.08-0.15	4.5-6.5 4.5-6.0 4.5-6.0 4.5-6.0	Low------------ Low------------ Low------------ Low------------	0.20 0.28 0.28 0.28	3	3	.5-2
Re---------------- Rembert	0-7 7-30 30-42 42-60	10-35 35-60 22-45 3-25	1.30-1.50 1.20-1.50 1.30-1.50 1.30-1.60	0.6-2.0 0.06-0.2 0.6-2.0 0.6-6.0	0.12-0.17 0.12-0.16 0.12-0.15 0.07-0.12	4.5-6.5 4.5-5.5 4.5-5.5 4.5-5.5	Low------------ Low------------ Low------------ Low------------	0.24 0.20 0.17 0.17	5	5	1-5
Sh---------------- Shellbluff	0-5 5-70	10-32 18-35	1.20-1.40 1.20-1.50	0.6-2.0 0.6-2.0	0.15-0.20 0.12-0.22	4.5-6.5 4.5-6.5	Low------------ Low------------	0.28 0.28	5	5	.5-3
To---------------- Toccoa	0-9 9-72	3-17 2-19	1.35-1.45 1.40-1.50	2.0-6.0 2.0-6.0	0.09-0.12 0.09-0.12	5.1-6.5 5.1-6.5	Low------------ Low------------	0.24 0.10	5	---	1-2
TrB, TrC, TrE---- Troup	0-60 60-80	1-10 15-35	--- ---	6.0-20 0.6-2.0	0.03-0.10 0.10-0.13	4.5-5.5 4.5-5.5	Very low------ Low------------	0.15 0.20	5	---	<1
UaB*: Udorthents.											
Arents.											
VaB--------------- Vaucluse	0-10 10-22 22-60 60-74	2-10 18-35 18-45 5-30	1.30-1.60 1.35-1.75 1.75-1.95 1.55-1.90	6.0-20 0.6-6.0 0.06-0.6 2.0-6.0	0.04-0.08 0.10-0.15 0.04-0.08 0.04-0.08	4.5-6.0 3.6-5.5 3.6-5.5 3.6-5.5	Low------------ Low------------ Low------------ Low------------	0.15 0.24 0.24 0.17	3	2	<1
VcD*, VcE*: Vaucluse----------	0-10 10-22 22-59 59-74	2-10 18-35 18-45 5-30	1.30-1.60 1.35-1.75 1.75-1.95 1.55-1.90	6.0-20 0.6-6.0 0.06-0.6 2.0-6.0	0.04-0.08 0.10-0.15 0.04-0.08 0.04-0.08	4.5-6.0 3.6-5.5 3.6-5.5 3.6-5.5	Low------------ Low------------ Low------------ Low------------	0.15 0.24 0.24 0.17	3	2	<1
Ailey-------------	0-23 23-30 30-72	5-10 15-30 18-32	--- --- ---	6.0-20 0.6-2.0 0.06-0.2	0.03-0.05 0.09-0.12 0.06-0.10	4.5-6.5 4.5-5.5 4.5-5.5	Low------------ Low------------ Low------------	0.15 0.24 0.17	4	---	<1
VuE*: Vaucluse----------	0-10 10-22 22-59 59-74	2-10 18-35 18-45 5-30	1.30-1.60 1.35-1.75 1.75-1.95 1.55-1.90	6.0-20 0.6-6.0 0.06-0.6 2.0-6.0	0.04-0.08 0.10-0.15 0.04-0.08 0.04-0.08	4.5-6.0 3.6-5.5 3.6-5.5 3.6-5.5	Low------------ Low------------ Low------------ Low------------	0.15 0.24 0.24 0.17	3	2	<1
Udorthents.											

See footnote at end of table.

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SOIL SURVEY OF

Alfalfa County, Oklahoma

United States Department of Agriculture
Soil Conservation Service
In cooperation with
Oklahoma Agricultural Experiment Station

Issued February 1975

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SOIL SURVEY OF ALFALFA COUNTY, OKLAHOMA

BY GLEN E. WILLIAMS AND EDWARD S. GROVER, SOIL CONSERVATION SERVICE

UNITED STATES DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE, IN COOPERATION WITH OK
HOMA AGRICULTURAL EXPERIMENT STATION

ALFALFA COUNTY is in the northern part of the State of Oklahoma, adjacent to the State of Kansas (fig. 1). Adjacent counties in Oklahoma are Grant, Garfield, Major, and Woods. Adjacent counties in Kansas, to the north, are Barber and Harper. Cherokee, in the central part of the county, is the county seat. The total area of the county is 554,880 acres.

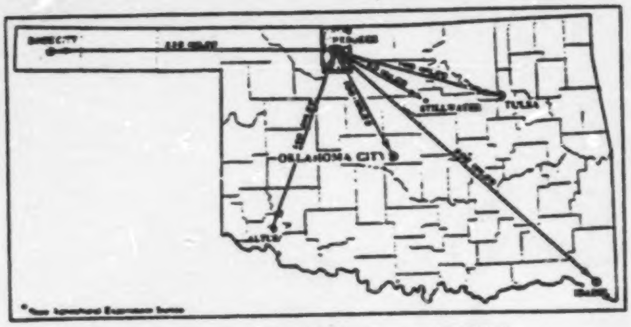

Figure 1.—Location of Alfalfa County in Oklahoma.

Farming is the main enterprise. A large part of the farm income is derived from sales of beef cattle and small grains, principally wheat, but alfalfa, sorghum, and grasses grown for tame pasture are important crops in some parts of the county. The size of farm units is expanding rapidly.

In a large part of the acreage, the soils have few limitations to use and are well suited to crops. More than 80 percent of the total acreage in farms consists of arable soils, although careful management is required if the sandy soils are cultivated. The soils in large areas are nearly level or very gently sloping, are loamy and fertile, and are easily farmed. Soils occupying several thousand acres, however, are affected, to some extent, by soluble salts.

The Pond Creek and Grant soils are used mainly to grow wheat. On many farms where these soils are dominant, wheat is used to graze beef cattle in winter. Alfalfa is grown on the Dale, Brewer, Reinach, and McLain soils.

How This Survey Was Made

Soil scientists made this survey to learn what kinds of soil are in Alfalfa County, where they are located, and how they can be used. The soil scientists went into county knowing they likely would find many soils t had already seen and perhaps some they had not. T observed the steepness, length, and shape of slopes, size and speed of streams, the kinds of native plant crops, the kinds of rock, and many facts about the s They dug many holes to expose soil profiles. A profi the sequence of natural layers, or horizons, in a soi extends from the surface down into the parent mat that has not been changed much by leaching or by action of plant roots.

The soil scientists made comparisons among the files they studied, and they compared these profiles those in counties nearby and in places more distant. classified and named the soils according to nation uniform procedures. The *soil series* and the *soil phas* categories of soil classification most used in a local su

Soils that have profiles almost alike make up a series. Except for different texture in the surface l all the soils of one series have major horizons that similar in thickness, arrangement, and other impo characteristics. Each soil series is named for a tow other geographic feature near the place where a so that series was first observed and mapped. Pond C and Drummond, for example, are the names of two series. All the soils in the United States having the s series name are essentially alike in those characteri that affect their behavior in the undisturbed landsc

Soils of one series can differ in texture of the sur layer and in slope, stoniness, or some other characte tic that affects use of the soils by man. On the bas such differences, a soil series is divided into phases. name of a soil phase indicates a feature that affects agement. For example, Grant silt loam, 1 to 3 pe slopes, is one of several phases within the Grant serie

After a guide for classifying and naming the soils been worked out, the soil scientists drew the bound of the individual soils on aerial photographs. These tographs show woodlands, buildings, field borders, and other details that help in drawing boundaries rately. The soil map at the back of this publication prepared from the aerial photographs.

The areas shown on a soil map are called ma units. On most maps detailed enough to be useful in ning the management of farms and fields, a mapping

TABLE 4.—*Estimated soil properties*

Soil series and map symbols	Depth to—		Depth from surface	Classification		
	Bed-rock	Seasonal high water table		USDA texture	Unified	AASHO[1]
*Quinlan: QwC, QwE For Woodward part, refer to Woodward series.	10-20	>72	0-16	Silt loam, loam, silty clay loam.	ML, CL-ML, or CL	A-4 or A-6
			16	Sandstone.		
Reinach:[2] Ra	>72	>72	0-75	Very fine sandy loam, silt loam.	ML, CL-ML, or CL	A-4
Renfrow: RcA	>60	>72	0-8	Silt loam	CL, CL-ML, or ML	A-4 or A-6
			8-14	Silty clay loam	CL, CH	A-6 or A-7
			14-65	Silty clay, silty clay loam, clay.	CL or CH	A-6 or A-7
Ruella: RuA	>72	>72	0-75	Loam	CL, CL-ML, or ML	A-4 or A-6
Salorthids: Sa. Too variable for valid estimates.						
Shellabarger: ShB	>72	>72	0-16	Fine sandy loam	SM, CL-ML, ML, or SM-SC	A-4
			16-42	Sandy clay loam	SC or CL	A-4 or A-6
			42-52	Sandy clay loam, fine sandy loam.	SC, SM, ML or CL	A-4 or A-6
			52-66	Fine sandy loam	SM, CL-ML, ML, or SM-SC	A-4
Tabler: TaA	>72	>72	0-10	Silty clay loam	CL	A-6 or A-7
			10-48	Silty clay, clay	CL or CH	A-7
			48-70	Silty clay loam, clay	CL or CH	A-6 or A-7
Tivoli: Tr	>72	>72	0-75	Fine sand	SM or SP-SM	A-2 or A-3
*Woodward: WuB For Quinlan part, refer to Quinlan series.	20-48	>72	0-27	Silt loam, loam, very fine sandy loam.	CL-ML or CL	A-4
			27-34	Sandstone.		
*Yahola:[2] Ya, Yp For Port part of Yp, refer to Port series.	>72	>60	0-75	Fine sandy loam, loam, very fine sandy loam.	SM, ML, CL-ML, or SM-SC	A-4

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[1] Based on AASHO Designation: M145-66I, in Interim Specifications and Methods adopted by the AASHO Committee on Materials 1966-67 (2).

[2] 100 percent of all soils passed the No. 4 sieve, except those of the Albion series, 32-75 inch layer. For Albion soils in the 32-75 inch layer, 70 to 90 percent passed the No. 4 sieve.

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significant to engineering—Continued

Percentage less than 3 inches in diameter passing sieve [1]—			Liquid limit	Plasticity index	Permeability	Available water capacity	Reaction	Salinity [1]	Shrink-swell potential	Corrosivity potential for—	
No. 10 (2.0 mm)	No. 40 (0.42 mm)	No. 200 (0.074 mm)								Uncoated steel	Concrete
					In/hr	*In/in of soil*	*pH*	*Mmhos/cm at 25° C.*			
100	96–100	65–98	21–40	1–20	2.0–6.0	0.15–0.24	7.4–8.4	--------	Low or moderate.	Low--------	Low.
100	94–100	50–97	<20	NP–10	0.6–2.0	0.13–0.24	6.6–8.4	--------	Low--------	Low--------	Low.
100	96–100	80–97	21–37	1–14	0.6–2.0	0.16–0.24	6.1–7.3	--------	Low--------	High--------	Low.
100	96–100	90–98	40–52	20–31	0.2–0.6	0.15–0.22	6.6–7.8	--------	Moderate.		
100	96–100	90–99	45–60	25–40	<0.06	0.12–0.22	6.6–8.4	--------	High.		
100	96–100	65–98	22–36	2–15	0.6–2.0	0.15–0.20	7.9–8.4	--------	Low--------	Low--------	Low.
98–100	95–100	36–60	<26	NP–6	2.0–6.0	0.11–0.15	5.6–6.5	--------	Low--------	Moderate---	Low.
98–100	90–100	36–65	25–33	8–15	0.6–2.0	0.12–0.17	6.1–7.8	--------	Low.		
98–100	90–100	36–65	<30	NP–15	0.6–6.0	0.11–0.17	6.6–8.4	--------	Low.		
98–100	94–100	36–60	NP–26	NP–6	2.0–6.0	0.11–0.15	6.6–8.4	--------	Low.		
100	96–100	90–98	35–50	13–26	0.2–0.6	0.18–0.22	6.1–7.3	--------	Moderate---	High--------	Low.
100	96–100	90–99	45–60	20–35	<0.06	0.12–0.18	6.6–8.4	--------	High.		
100	96–100	90–98	40–60	15–35	<0.06	0.12–0.22	7.9–8.4	--------	Moderate to high.		
98–100	82–98	10–20	--------	NP	6.0–20.0	0.05–0.11	6.1–7.8	--------	Low--------	Low--------	Low.
100	94–100	50–90	20–30	4–10	0.6–2.0	0.13–0.24	6.6–8.4	--------	Low--------	Low--------	Low.
98–100	94–100	36–70	<26	NP–6	2.0–6.0	0.07–0.20	7.9–8.4	--------	Low--------	Low--------	Low.

---

[1] Values are based on electrical conductivity of the saturation extract and have the following meanings for salinity class: Less than 2.0 none; 2.0–4.0, low; 4.0–8.0, moderate; 8.0–16.0, high; more than 16.0, very high.

[2] NP means nonplastic.

[3] Subject to flooding.

[4] Below depth of 40 inches.

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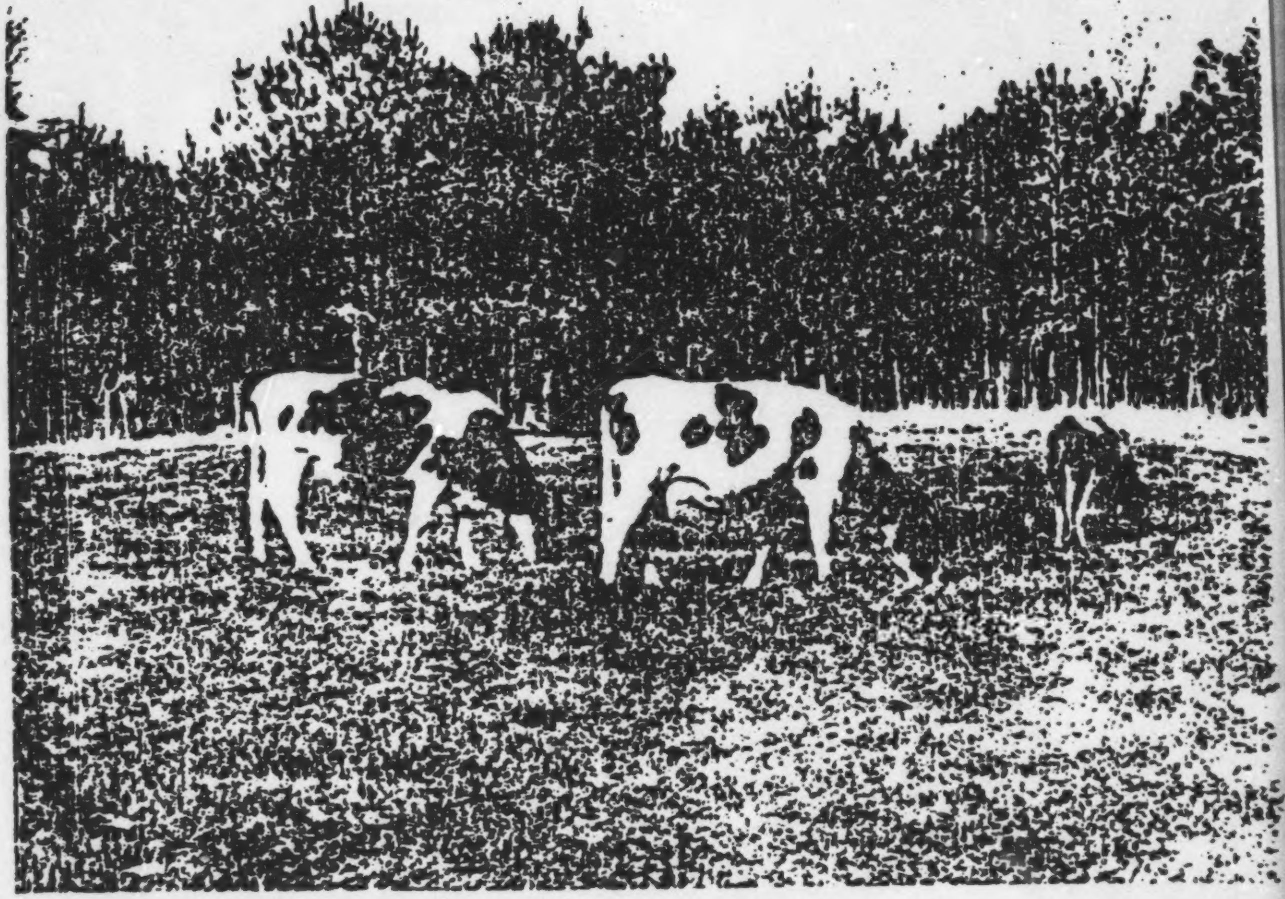
SOIL SURVEY O

Amite County, Mississipp



United States Department of Agriculture
Soil Conservation Service and Forest Service
In cooperation with
Mississippi Agricultural and Forestry Experiment Station

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SOIL SURVEY OF AMITE COUNTY, MISSISSIPPI

BY ALLAN C. MILBRANDT, SOIL CONSERVATION SERVICE

UNITED STATES DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE AND FOREST SERVICE, IN COOPERATION WITH THE MISSISSIPPI AGRICULTURAL AND FORESTRY EXPERIMENT STATION

AMITE COUNTY is in the southwestern part of Mississippi (fig. 1). It has a land area of 466,560 acres, or 729 square miles. The county is rectangular. It is about 24 miles wide from north to south and about 30 miles long from east to west. The southern boundary is 31° north latitude.

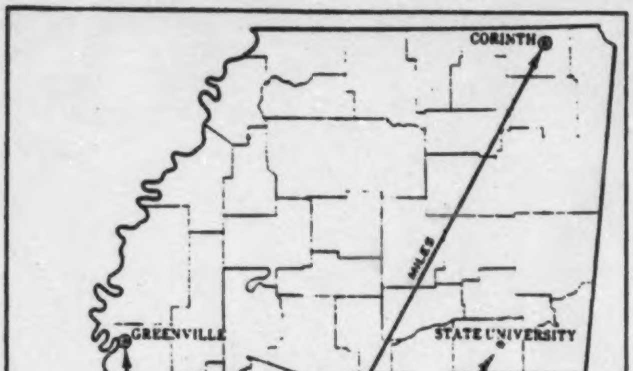

Figure 1.—Location of Amite County in Mississippi.

Raising beef cattle, dairying, and managing wood crops are the main enterprises. Some field crops are also grown. The petroleum industry and other industries produce large amounts of income. Garment factories and wood-using plants are the largest industrial installations in the county. Many employees of industrial plants are also part-time farmers.

How This Survey Was Made

Soil scientists made this survey to learn what kinds of soil are in Amite County, where they are located, and how they can be used. The soil scientists went into the county knowing they likely would find many soils they had already seen and perhaps some they had not. They observed the steepness, length, and shape of slopes, the size and speed of streams, the kinds of native plants or crops, the kinds of rock, and many facts about the soils. They dug many holes to expose soil profiles. A profile is the sequence of natural layers, or horizons, in a soil; it extends from the surface down into the parent material that has not been changed much by leaching or by the action of plant roots.

The soil scientists made comparisons among the profiles they studied, and they compared these profiles with those in counties nearby and in places more distant. They classified and named the soils according to nationwide, uniform procedures. The *soil series* and the *soil phase* are the categories of soil classification most used in a local survey.

Soils that have profiles almost alike make up a soil series. Except for different texture in the surface layer, all the soils of one series have major horizons that are similar in thickness, arrangement, and other important characteristics. Each soil series is named for a town or other geographic feature near the place where a soil of that series was first observed and mapped. Providence and Ruston, for example, are the names of two soil series. All the soils in the United States having the same series name are essentially alike in those characteristics that affect their behavior in the undisturbed landscape.

gently sloping to strongly sloping soils generally do not.

Irrigation systems are affected by such features as slope, erodibility, permeability, and drainage.

Terraces and diversions are essential in places to help control erosion and to help protect downslope areas from runoff. Shallowness of the soils and irregular and steep topography are among the unfavorable features.

Waterways for agricultural drainage and control of

TABLE 6.—*Estimates of soil propertie*

[An asterisk in the first column indicates that at least one mapping unit in this series is made up of two or more kinds of soil. The soils in such to other series that appear in the first column

Soil series and map symbols	Depth to seasonal high water table	Depth from surface	USDA texture	Classification	
				Unified	AASHO
		Inches			
Ariel: Ar	About 24 inches in winter and in spring.	0-30	Silt loam	ML or ML-CL	A-4
		30-65	Silt loam	ML or CL	A-4 or A-6
Bruno: Br	More than 40 inches.	0-8	Loamy fine sand	SM	A-2
		8-16	Silt loam and very fine sandy loam.	ML	A-4
		16-22	Loamy fine sand	SM	A-2
		22-58	Loamy sand, sand, silt loam, and very fine sandy loam.	SM, ML	A-2, A-4
Bude: Bu	Less than 12 inches to a perched water table during a period of high rainfall.	0-5	Silt loam	ML or CL	A-4
		5-16	Silt loam	ML or CL	A-6
		16-36	Silt loam	ML or CL	A-4
		36-60	Silt loam	ML or CL	A-4
Collins: Co	About 30 inches in winter and early spring.	0-42	Silt loam	ML or ML-CL	A-4
		42-48	Very fine sandy loam	ML	A-4
Gillsburg: Gb	About 20 inches in winter and in spring.	0-42	Silt loam	ML or CL	A-4
		42-65	Silt loam	ML-CL	A-4
Ora: OrB, OrB3, OrC, OrC3.	About 23 inches to a perched water table during prolonged rainfall.	0-9	Loam	SM	A-4
		9-23	Clay loam	CL	A-6
		23-39	Loam and clay loam	CL	A-6
		39-68	Loam	CL	A-7, A-6
Peoria: Pe	At or near the surface in winter and in spring.	0-18	Silt loam and silt	ML	A-4
		18-36	Silt and silt loam	ML or CL	A-4
		36-72	Silt loam	ML or CL	A-4
Providence: PrB, PrB3, PrC, PrC3.	About 22 inches to perched water table during a wet period.	0-5	Silt loam	ML	A-4
		5-22	Silty clay loam	CL	A-7 or A-6
		22-38	Silty clay loam and silt loam	CL	A-6
		38-70	Sandy loam	SC	A-4
Ruston: RuA, RuB, RuB3, RuC, RuC3.	More than 60 inches.	0-12	Sandy loam	SM or ML	A-4 or A-2
		12-37	Sandy clay loam	SC or CL	A-6
		37-54	Sandy loam	SM	A-2 or A-4
		54-85	Sandy clay loam and sandy loam.	SC or CL	A-6 or A-4
Saffell: SaD, SaE	More than 60 inches.	0-11	Gravelly sandy loam	SM or ML	A-2 or A-4
		11-17	Gravelly sandy clay loam	GC	A-2 or A-4
		17-42	Gravelly sandy loam	GM or SM	A-2
		42-80	Gravelly loamy sand	GM or SM	A-2
Smithdale: SmD, SmD3, SmE, SmE3.	More than 60 inches.	0-12	Sandy loam	SM, ML	A-4 or A-2
		12-46	Sandy clay loam	CL, SC	A-6
		46-84	Sandy loam	SM	A-4 or A-2
*Susquehanna: SsE For Smithdale part, see Smithdale series.	More than 30 inches.[1]	0-7	Silt loam	ML or CL	A-4 or A-6
		7-80	Clay	CH	A-7

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[1] The ratings in this column should not be construed to be the coefficient of permeability, *k*-value, used by engineers.

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erosion are generally required for soils on flood plains and for nearly level soils on uplands. The erodibility of the soil affects shaping, seeding, and establishing waterways, and a seasonal high water table limits the use of equipment.

Use of the Soils for Town and Country Planning

The proximity of Amite County to Baton Rouge, Louisiana, and the easy access to all parts of the county by State and U.S. Highways have contributed

significant in engineering

mapping units may have different properties and limitations, and for this reason it is necessary to follow carefully the instructions for referring of this table. The sign < means less than]

Percentage passing sieve—				Permeability [1]	Available water capacity	Reaction	Shrink-swell potential
No 4 (4.7 mm)	No 10 (2.0 mm)	No 40 (0.42 mm)	No 200 (0.074 mm)				
				Inches per hour	*Inches per inch of soil*	*pH*	
		100	90-100	0.63-2.0	0.20-0.22	4.5-5.5	Low
	100	95-100	85-100	0.2-0.63	0.16-0.20	4.5-5.5	Low.
	100	80-95	10-30	2.0-6.3	0.05-0.10	5.1-7.3	Low.
	100	100	90-100	2.0-6.3	0.15-0.20	5.1-7.3	Low.
	100	80-95	10-30	2.0-6.3	0.05-0.10	5.1-7.3	Low.
	100	80-90	10-60	2.0-20	0.05-0.10	5.1-7.3	Low.
	100	95-100	85-100	0.63-2.0	0.20-0.23	5.1-5.5	Low.
	100	95-100	35-100	0.63-2.0	0.18-0.20	4.5-5.5	Low.
	100	95-100	85-95	0.2-0.63	0.05-0.10	4.5-5.5	Low.
	100	95-100	70-80	0.2-0.63	0.05-0.10	4.5-5.5	Low.
		100	90-100	0.63-2.0	0.20-0.23	4.5-5.5	Low.
		100	85-95	0.63-2.0	0.18-0.20	4.5-5.5	Low.
		100	90-100	0.63-2.0	0.19-0.22	4.5-5.5	Low.
		100	90-100	0.2-0.63	0.14-0.17	4.5-5.5	Low.
	100	70-85	36-45	2.0-6.3	0.10-0.13	4.5-5.5	Low.
	100	80-100	50-95	0.63-2.0	0.12-0.18	4.5-5.5	Low.
	100	80-100	50-90	0.2-0.63	0.05-0.10	4.5-5.5	Low.
	100	90-100	50-90	0.2-0.63	0.05-0.10	4.5-5.5	Low to moderate.
	100	95-100	90-100	0.2-0.63	0.18-0.22	4.5-5.5	Low.
	100	100	90-100	0.06-0.2	0.18-0.20	4.5-5.5	Low.
	100	90-100	85-95	0.06-0.2	0.12-0.16	4.5-5.5	Low.
		100	85-100	0.63-2.0	0.20-0.22	4.5-5.5	Low.
	100	95-100	85-100	0.63-2.0	0.20-0.22	4.5-5.5	Moderate.
	100	90-100	70-90	0.2-0.63	0.05-0.10	4.5-5.5	Low.
100	90-100	60-70	36-50	0.2-0.63	0.05-0.10	4.5-5.5	Low.
	100	70-95	30-60	0.63-2.0	0.10-0.15	4.5-5.5	Low.
	100	80-90	35-75	0.63-2.0	0.15-0.17	4.5-5.5	Low.
	100	70-95	30-50	0.63-2.0	0.10-0.15	4.5-5.5	Low.
	100	75-95	36-55	0.63-2.0	0.14-0.18	4.5-5.5	Low.
75-90	75-85	40-60	20-55	2.0-6.3	0.10-0.12	4.5-5.5	Low.
40-65	40-60	40-55	25-45	0.63-2.0	0.10-0.15	4.5-5.5	Low.
35-60	30-55	30-50	15-30	2.0-6.3	0.10-0.12	4.5-5.5	Low.
35-60	30-50	30-45	15-25	6.3-20	0.04-0.06	4.5-5.5	Low.
	100	70-95	25-55	2.0-6.3	0.10-0.15	4.5-5.5	Low.
	100	80-90	40-55	0.63-2.0	0.15-0.17	4.5-5.5	Low.
	100	70-95	25-45	2.0-6.3	0.10-0.15	4.5-5.5	Low.
	100	85-100	70-90	0.63-2.0	0.16-0.18	4.5-5.5	Low.
	100	80-100	75-90	<0.06	0.15-0.20	4.5-5.5	High.

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[1] This soil is saturated by water in some seasons.

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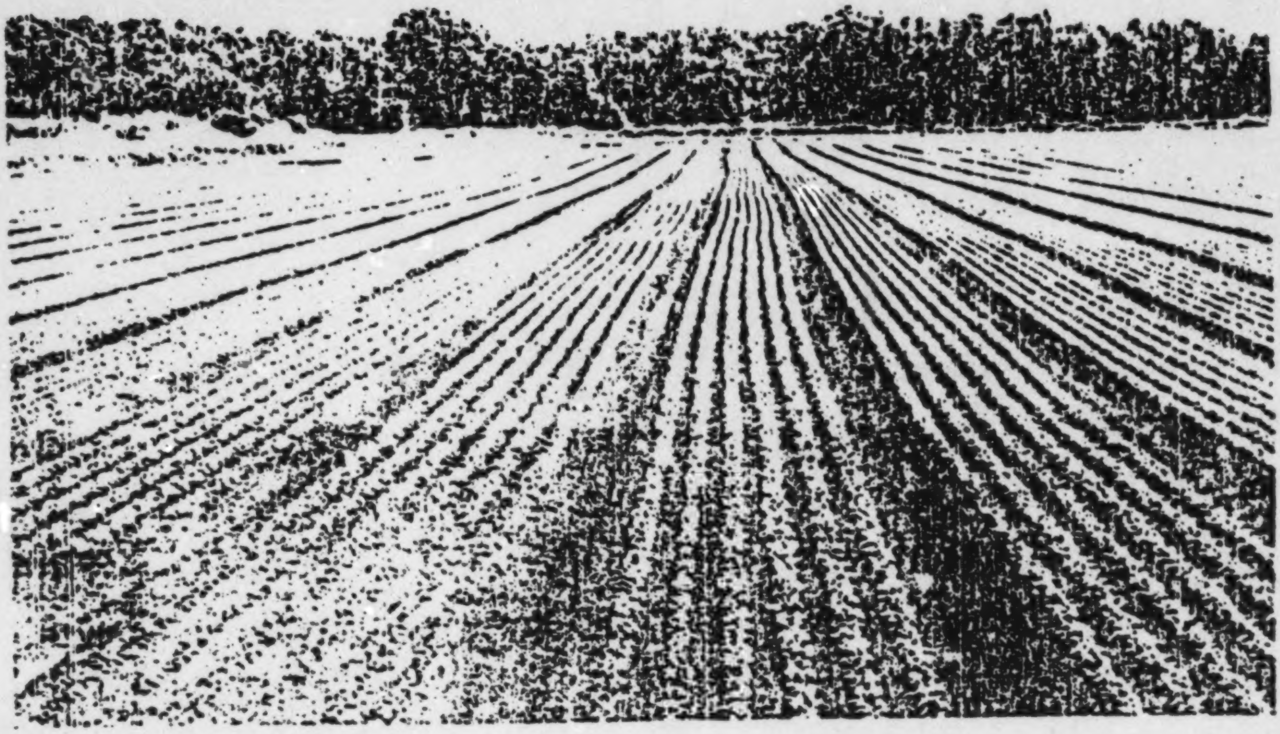
SOIL SURVEY OF

Anoka County, Minnesota



United States Department of Agriculture
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SOIL SURVEY OF ANOKA COUNTY, MINNESOTA

BY LEON M. CHAMBERLAIN, SOIL CONSERVATION SERVICE

FIELDWORK BY LEON M. CHAMBERLAIN, ROBERT A. LUETH, DARWIN G. PRESTON, PAUL E. RASMUSSEN,
CHARLES K. SUTTON, MARTIN G. ZIEBELL
SOIL CONSERVATION SERVICE

UNITED STATES DEPARTMENT OF AGRICULTURE IN COOPERATION WITH THE
UNIVERSITY OF MINNESOTA AGRICULTURAL EXPERIMENT STATION

ANOKA COUNTY is in the east-central part of Minnesota (fig. 1). It has a total land area of 272,000 acres, or 422 square miles. Anoka is the county seat.

Although this is the soil survey of Anoka County, a large acreage, approximately 10,000 acres, in the southern part, namely, the cities of Columbia Heights and Fridley, a small part of Coon Rapids, and the Village of Spring Lake Park, was excluded from this survey. The reworking of the soil during urban construction made it impractical to classify the soils. Onsite investigation is needed to determine soil characteristics in these urban areas.

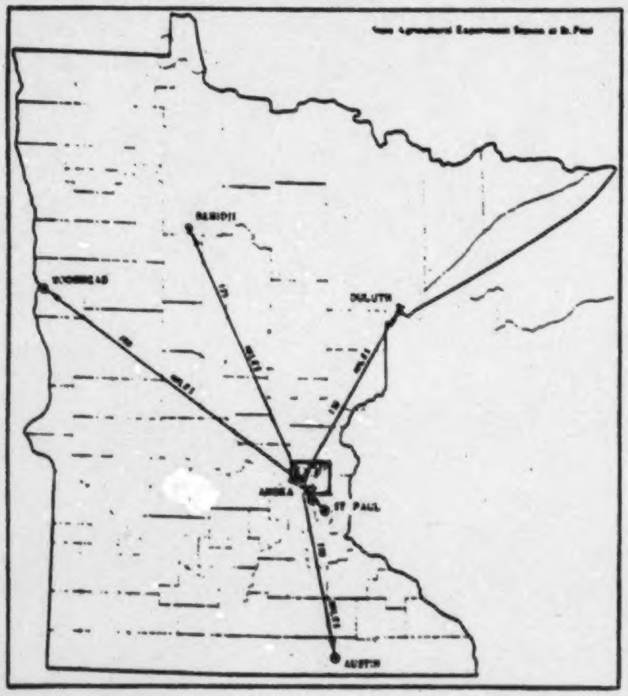

Figure 1.—Location of Anoka County in Minnesota.

Since 1950, the suburban communities in the Twin City metropolitan area have expanded rapidly and farming has declined. In 1972, only about 30 percent of the land was farmed; 20 percent was cropped to corn, soybeans, and small grain.

How This Survey Was Made

Soil scientists made this survey to learn what kinds of soil are in Anoka County, where they are located, and how they can be used. The soil scientists went into the county knowing they likely would find many soils they had already seen and perhaps some they had not. They observed the steepness, length, and shape of slopes, the size and speed of streams, the kinds of native plants or crops, the kinds of rock, and many facts about the soils. They dug many holes to expose soil profiles. A profile is the sequence of natural layers, or horizons, in a soil; it extends from the surface down into the parent material that has not been changed much by leaching or by the action of plant roots.

The soil scientists made comparisons among the profiles they studied, and they compared these profiles with those in counties nearby and in places more distant. They classified and named the soils according to nationwide, uniform procedures. The *soil series* and the *soil phase* are the categories of soil classification most used in a local survey.

Soils that have profiles almost alike make up a soil series. Except for different texture in the surface layer, all the soils of one series have major horizons that are similar in thickness, arrangement, and other important characteristics. Each soil series is named for a town or other geographic feature near the place where a soil of that series was first observed and mapped. Isanti and Lino, for example, are the names of two soil series. All the soils in the United States having the same series name are essentially alike in those characteristics that affect their behavior in the undisturbed landscape.

Soils of one series can differ in texture of the surface *significant in engineering*—Continued

Percentage less than 3 inches passing sieve—cont.		Liquid limit	Plasticity index	Permeability	Available water capacity[1]	Reaction	Shrink-swell potential	Risk of corrosion to—	
No. 40 (0.42 mm)	No. 200 (0.074 mm)							Uncoated steel	Concrete
		Pct		*In/hr*	*In/in of soil*	*pH*			
-------	-------	-------	-------	2.0- 6.0	0.48–0.58	5.6–7.3	-------	High	Moderate.
-------	-------	-------	-------	2.0- 6.0	0.35–0.48	7.4–7.8	-------	High	Low.
-------	-------	-------	-------	0.2- 0.6	0.35–0.48	7.4–7.8	-------	High	Low.
-------	-------	-------	-------	0.06- 0.2	0.20–0.22	7.4–7.8	-------	High	Low.
70–80	25–40	15–20	1–4	0.6- 2.0	0.16–0.18	5.1–6.0	Low	Moderate	Moderate.
60–70	30–50	15–20	1–4	0.2- 0.6	0.12–0.14	5.1–6.5	Low	Moderate	Moderate.
65–75	25–40	10–20	1–4	0.2- 0.6	0.09–0.11	6.6–7.3	Low	Moderate	Low.
95–100	5–15	-------	NP	6.0–20.0	0.07–0.09	4.5–5.0	Low	Low	High.
95–100	15–20	-------	NP	6.0–20.0	0.06–0.08	5.6–6.0	Low	Low	Moderate.
95–100	5–15	-------	NP	6.0–20.0	0.05–0.07	5.6–6.5	Low	Low	Moderate.
-------	-------	-------	-------	2.0- 6.0	0.35–0.48	6.6–7.3	-------	High	Low.
95–100	15–30	-------	NP	6.0–20.0	0.07–0.09	5.1–6.0	Low	Low	High.
95–100	12–35	-------	NP	6.0–20.0	0.06–0.11	5.1–6.0	Low	Low	Moderate.
90–100	12–20	-------	NP	6.0–20.0	0.05–0.07	5.6–6.0	Low	Low	Moderate.
85–90	60–75	25–35	8–20	0.6- 2.0	0.20–0.22	6.6–7.3	Moderate	High	Low.
90–100	60–80	30–40	15–30	0.6- 2.0	0.15–0.19	6.6–7.8	Moderate	High	Low.
85–90	50–75	25–35	7–20	0.6- 2.0	0.17–0.19	7.9–8.4	Moderate	High	Low.
95–100	10–20	-------	NP	6.0–20.0	0.07–0.09	5.1–6.0	Low	Low	Moderate.
95–100	5–20	-------	NP	6.0–20.0	0.06–0.08	6.1–7.3	Low	Low	Moderate.

foot traffic. The best soils have a nearly level surface free of coarse fragments and rock outcrop, good drainage, no flooding during periods of heavy use, and a surface that is firm after rains but not dusty when dry. If grading and leveling are required, depth to rock is important.

Paths and trails are used for local and cross-country travel by foot or on horseback. Design and layout should require little or no cutting and filling. The best soils are at least moderately well drained, are firm when wet but not dusty when dry, are flooded no more than once during the season of use, have slopes of less than 18 percent, and have few or no rocks or stones on the surface.

The outdoor recreation groups of Anoka County are described in table 4.

Crops and Pasture

Fewer acres are cropped each year because of the rapid urbanization of Anoka County. Corn, soybeans, alfalfa, oats, and rye are the chief crops. Cultured sod, carrots, radishes, and potatoes are grown on some organic soils. Controlling erosion, increasing fertility, maintaining and improving drainage, and conserving moisture in the droughtier soils are the main considerations in managing the cultivated soils in the county.

Stripcropping, contouring, terraces, grassed waterways, minimum tillage, no-till planting, cover crops, field windbreaks, returning crop residue, and raising sod crops in the cropping sequence help in erosion control.

Applying commercial fertilizers and barnyard manure and growing legumes and green-manure crops improve or maintain fertility. Fertilizer should be carefully applied according to soil fertility tests. An excessive application of commercial fertilizer can run off into streams and lakes and infiltrate into underground water supplies. This is also true of insecticides and herbicides.

Drainage is needed on the wet, level or depressional soils if these soils are to be intensively cropped. Outlets are needed for lateral ditches and tile drains. Periodic

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SOIL SURVEY OF

Clay County, Arkansas

United States Department of Agriculture
Soil Conservation Service
In cooperation with
Arkansas Agricultural Experiment Station

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SOIL SURVEY OF CLAY COUNTY, ARKANSAS

Soils surveyed by Richard T. Fielder, Dick V. Ferguson, and Jerry L. Hogan,
Soil Conservation Service

United States Department of Agriculture, Soil Conservation Service,
in cooperation with the Arkansas Agricultural Experiment Station

CLAY COUNTY is in the northeastern part of Arkansas. (See facing page.) It is roughly rectangular in shape and has a land area of about 409,088 acres, or 639 square miles. It is about 20 miles from north to south and about 38 miles from east to west.

The county is bounded on the north and east by the State of Missouri, on the south by Greene County, and on the west by Randolph County.

In 1970 the population of Clay County was 18,771. Piggott with a population of 3,361 and Corning with a population of 3,156 are the county seats and important trading centers. Rector has a population of 2,218 and is also an important trading center.

The economy of the county is based on farming. Except for a few manufacturing plants in Corning, Piggott, and Rector, most of the business provides farm services.

General nature of the county

The farming, physiography, drainage, and climate of Clay County are discussed in this section.

Uplands, where the soils formed in thick layers of windblown sediment, make up about 22 percent of the county. The uplands lie across the east central part of the county from north to south. Most of the uplands are on Crowley's Ridge.

Except for the steep slopes on Crowley's Ridge, most of the upland soils are suitable for cultivation or improved pasture. Just as excess water is a moderate to severe hazard where soils are level, so erosion is a moderate to severe hazard where they are more sloping.

About 78 percent of the county is bottom land and associated lakes and rivers east and west of Crowley's Ridge. The soils in this area are suited to farming. Except for a few large wooded tracts such as those within the Black River Wildlife Management Area in the southwestern part of the county, most of the area is cultivated. Excess water drains away slowly or is ponded, and it is a moderate to severe hazard over the area. Erosion is significant in a few places.

Elevations above mean sea level in the county rang from about 524 feet at a point about 3 miles north Rector atop Crowley's Ridge to about 240 feet near th southeast boundary of the county along the St. Franc River.

Most of the soils in the county contain moderate to hig amounts of plant nutrients and are among the most fe tile soils in the state. The bottom land area is part of th combined flood plains of the St. Francis, Cache, Litt Black, Black, and Current Rivers. Most of the botto land was subject to flooding by these rivers until leve were constructed. Levees along the St. Francis and Bla Rivers protect part of the area from flooding. Since the levees were constructed, major flooding has been neglig ble except in areas between the rivers and their leve and along Cache River Ditch and its tributaries. Even the areas subject to frequent flooding, which includ about 9 percent of the land area, floods occur main between January and June. Thus, warm-season crops c be grown most years.

Farming

Farming in Clay County spreads from the bette drained parts of the uplands to the higher parts of th natural levees, then gradually to the poorly drained flats According to the 1969 Census of Agriculture, abou 345,521 acres, or 85 percent of the county, is in farm The rest is woodland, cities and towns, state owned la and transportation and utility facilities. The early eco my was based on the plantation system, and cotton w the main cash crop.

Farming is still the principal means of livelihood, b cropping systems have become more diversified. T acreage of cotton, corn, and other feed crops has declin in importance and soybeans and small grains have i creased in importance.

Most farming in Clay County is of a general natur Soybeans, cotton, and wheat are the main crops, and so rice and grain sorghum are grown. Beef cattle are rais on some farms. Table 1 shows the acreage of princip

TABLE 16.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS

[The symbol < means less than; > means more than. Entries under "Erosion factors--T" apply to the entire profile. Absence of an entry means data were not available or were not estimated]

Soil name and map symbol	Depth	Permea-bility	Available water capacity	Soil reaction	Salinity	Shrink-swell potential	Risk of corrosion		Erosion factors	
							Uncoated steel	Concrete	K	T
	In	In/hr	In/in	pH	Mmhos/cm					
Amagon: 10, [1]11	0-6	0.6-2.0	0.16-0.24	4.5-6.0	<2	Low	High	High	0.43	5
	6-25	0.2-0.6	0.16-0.24	4.5-6.5	<2	Low	High	High	0.43	
	25-44	0.06-0.2	0.16-0.24	4.5-6.5	<2	Moderate	High	High	0.37	
	44-72	0.06-0.6	0.15-0.24	5.1-8.4	<2	Low	High	High	0.43	
Beulah: 12, 13	0-7	2.0-6.0	0.10-0.15	4.5-6.0	<2	Low	Low	Moderate	0.20	5
	7-39	2.0-6.0	0.10-0.20	4.5-6.0	<2	Low	Low	Moderate	0.20	
	39-72	>6.0	0.02-0.15	5.1-7.3	<2	Low	Low	Moderate	0.17	
Bonn: [1]14: Bonn part	0-4	0.2-0.6	0.15-0.23	4.5-7.3	<2	Low	High	Low	0.49	3
	4-38	<0.06	0.08-0.14	5.6-9.0	<2	Low	High	Low	0.49	
	38-72	<0.2	0.08-0.14	6.6-9.0	<2	Low	High	Low	0.49	
Foley part	0-10	0.6-2.0	0.13-0.24	4.5-7.3	<2	Low	High	Low	0.43	3
	10-16	0.2-0.6	0.18-0.24	5.1-7.3	<2	Moderate	High	Low	0.43	
	16-54	<0.06	0.10-0.14	5.1-9.0	<2	Moderate	High	Low	0.43	
	54-72	<0.06	0.10-0.14	6.6-9.0	<2	Low	High	Low	0.49	
Bosket: 15, 16	0-18	2.0-6.0	0.10-0.15	5.1-6.5	<2	Low	Low	Moderate	0.24	4
	18-42	0.6-2.0	0.10-0.20	5.1-6.5	<2	Low	Low	Moderate	0.32	
	42-72	2.0-6.0	0.10-0.15	5.1-6.5	<2	Low	Low	Moderate	0.32	
Brandon: 17	0-9	0.6-2.0	0.18-0.23	4.5-5.5	<2	Low	Moderate	High	0.37	3
	9-50	0.6-2.0	0.18-0.23	4.5-5.5	<2	Low	Moderate	High	0.23	
	50-72	2.0-20.0	0.05-0.12	4.5-5.5	<2	Low	Low	High	0.17	
[1]18: Brandon part	0-9	0.6-2.0	0.18-0.23	4.5-5.5	<2	Low	Moderate	High	0.37	3
	9-50	0.6-2.0	0.18-0.23	4.5-5.5	<2	Low	Moderate	High	0.23	
	50-72	2.0-20.0	0.05-0.12	4.5-5.5	<2	Low	Low	High	0.17	
Saffell part	0-10	2.0-6.0	0.05-0.10	4.5-5.5	<2	Low	Low	Moderate	0.20	4
	10-41	0.6-2.0	0.06-0.10	4.5-5.5	<2	Low	Low	Moderate	0.28	
	41-72	0.6-2.0	0.06-0.12	4.5-5.5	<2	Low	Low	Moderate	0.17	
Calhoun: 19	0-14	0.2-0.6	0.21-0.23	4.5-6.0	<2	Low	High	Moderate	[illegible]	3
	14-37	0.06-0.2	0.20-0.22	4.5-5.5	<2	Moderate	High	Moderate	0.43	
	37-72	0.2-0.6	0.21-0.23	4.5-7.8	<2	Low	High	Moderate	0.43	
Collins: 20	0-6	0.6-2.0	0.10-0.20	4.5-5.5	<2	Low	Moderate	Moderate	0.43	5
	6-72	0.6-2.0	0.20-0.24	4.5-5.5	<2	Low	Moderate	Moderate	0.43	
Commerce: [1]21	0-8	0.6-2.0	0.21-0.23	5.6-7.8	<2	Low	High	Low	0.37	5
	8-30	0.2-0.6	0.20-0.22	6.1-8.4	<2	Moderate	High	Low	0.32	
	30-72	0.2-2.0	0.20-0.23	6.6-8.4	<2	Low	High	Low	0.37	
Crowley: 22	0-15	0.2-0.6	0.20-0.23	4.5-7.3	<2	Low	High	Moderate	0.43	4
	15-32	<0.06	0.19-0.21	4.5-6.5	<2	High	High	Moderate	0.32	
	32-72	0.06-0.2	0.20-0.22	5.6-8.4	<2	Moderate	High	Moderate	0.32	

See footnote at end of table.

TABLE 16.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS--Continued

Soil name and map symbol	Depth	Permea-bility	Available water capacity	Soil reaction	Salinity	Shrink-swell potential	Risk of corrosion		Erosion factors	
							Uncoated steel	Concrete	K	T
	In	In/hr	In/in	pH	Mmhos/cm					
Dexter:										
23	0-7	0.6-2.0	0.15-0.24	5.1-6.5	<2	Low	Low	Moderate	0.37	5
	7-40	0.6-2.0	0.15-0.24	4.5-6.0	<2	Low	Moderate	Moderate	0.32	
	40-72	0.6-6.0	0.03-0.18	4.5-5.5	<2	Low	Low	Moderate	0.24	
Dubbs:										
24	0-8	0.6-2.0	0.20-0.22	4.5-6.0	<2	Low	Moderate	Moderate	0.37	5
	8-37	0.6-2.0	0.18-0.22	4.5-6.0	<2	Moderate	Moderate	Moderate	0.37	
	37-72	2.0-6.0	0.20-0.22	4.5-6.0	<2	Low	Moderate	Moderate	0.37	
Dundee:										
25	0-7	0.6-2.0	0.15-0.20	4.5-6.0	<2	Low	High	Moderate	0.37	5
	7-31	0.2-0.6	0.15-0.20	4.5-6.0	<2	Moderate	High	Moderate	0.37	
	31-72	0.6-2.0	0.15-0.20	4.5-7.3	<2	Low	High	Moderate	0.37	
Falaya:										
26	0-41	0.6-2.0	0.20-0.22	4.5-5.5	<2	Low	High	Moderate	0.43	5
	41-72	0.06-2.0	0.14-0.22	4.5-5.5	<2	Low	High	Moderate	0.43	
Foley:										
27	0-10	0.6-2.0	0.13-0.24	4.5-7.3	<2	Low	High	Low	0.43	3
	10-16	0.2-0.6	0.18-0.24	5.1-7.3	<2	Moderate	High	Low	0.43	
	16-54	<0.06	0.10-0.14	5.1-9.0	<2	Moderate	High	Low	0.43	
	54-72	<0.06	0.10-0.14	5.6-9.0	<2	Low	High	Low	0.49	
Fountain:										
23	0-17	0.2-0.6	0.20-0.23	5.6-7.8	<2	Low	High	Low	0.37	3
	17-60	0.2-0.6	0.20-0.22	6.6-7.8	<2	Moderate	High	Low	0.37	
	60-72	0.2-0.6	0.21-0.23	6.6-8.4	<2	Low	High	Low	0.37	
Jackport:										
29	0-5	0.2-0.6	0.18-0.22	4.5-6.0	<2	Moderate	High	High	0.43	5
	5-16	<0.06	0.12-0.18	4.5-5.5	<2	High	High	High	0.32	
	16-37	<0.06	0.12-0.18	4.5-5.5	<2	High	High	High	0.32	
	37-72	<0.06	0.12-0.18	4.5-7.8	<2	High	High	High	0.32	
Kobel:										
30	0-5	<0.06	0.14-0.18	5.1-7.3	<2	High	High	Moderate	0.37	5
	5-55	<0.06	0.12-0.22	6.1-8.4	<2	High	High	Low	0.37	
	55-72	0.06-0.2	0.14-0.22	6.6-8.4	<2	High	High	Low	0.37	
[1]31	0-5	0.6-2.0	0.16-0.24	5.1-7.3	<2	Low	High	Moderate	0.49	5
	5-55	<0.06	0.12-0.22	6.1-8.4	<2	High	High	Low	0.37	
	55-72	0.06-0.2	0.14-0.22	6.6-8.4	<2	High	High	Low	0.37	
Loring:										
32, 33, 34	0-8	0.6-2.0	0.20-0.23	5.1-6.0	<2	Low	Moderate	Moderate	0.49	4
	8-27	0.6-2.0	0.20-0.22	5.1-6.0	<2	Low	Moderate	Moderate	0.43	
	27-52	0.2-0.6	0.06-0.13	5.1-6.0	<2	Low	Moderate	Moderate	0.43	
	52-72	0.6-2.0	0.06-0.13	5.1-6.5	<2	Low	Moderate	Low	0.43	
Memphis:										
[1]35	0-10	0.6-2.0	0.20-0.23	4.5-6.0	<2	Low	Low	Moderate	0.37	5
	10-48	0.6-2.0	0.20-0.22	4.5-6.0	<2	Low	Moderate	Moderate	0.37	
	48-72	0.6-2.0	0.20-0.23	4.5-6.0	<2	Low	Low	Moderate	0.37	
Patterson:										
36	0-11	2.0-6.0	0.11-0.15	4.5-6.0	<2	Low	Moderate	Moderate	0.20	5
	11-43	2.0-6.0	0.12-0.16	4.5-5.5	<2	Low	Moderate	Moderate	0.20	
	43-72	>6.0	0.06-0.10	4.5-7.3	<2	Low	Moderate	Moderate	0.17	
Tuckerman:										
37	0-8	0.6-2.0	0.11-0.15	4.5-6.0	<2	Low	High	Moderate	0.24	5
	8-14	0.6-2.0	0.11-0.20	4.5-6.0	<2	Low	High	Moderate	0.24	
	14-42	0.2-0.6	0.12-0.20	4.5-6.0	<2	Low	High	Moderate	0.32	
	42-72	0.6-2.0	0.11-0.20	4.5-6.0	<2	Low	High	Moderate	0.24	

See footnote at end of table.

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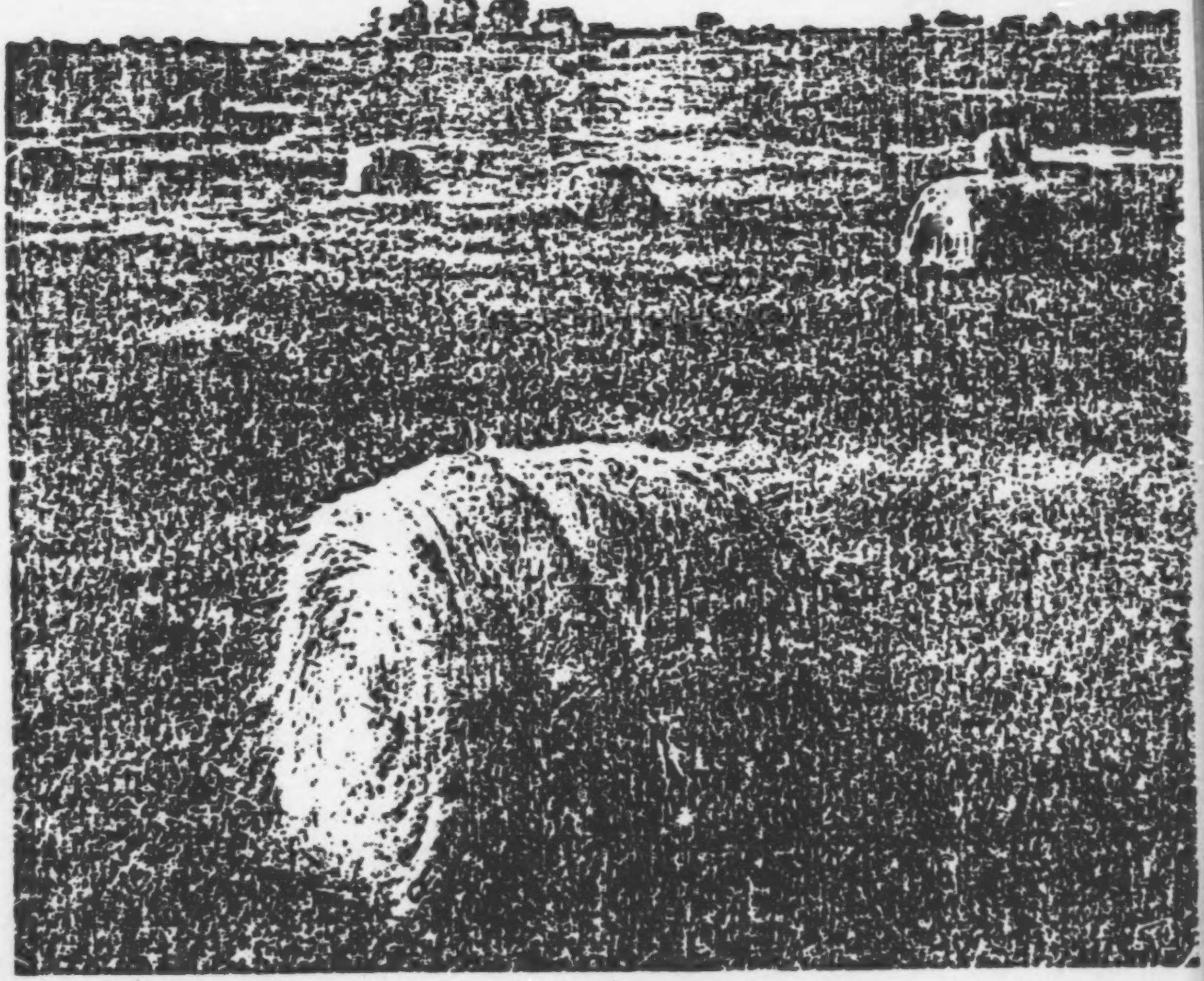
United States
Department of
Agriculture

Soil
Conservation
Service

In cooperation with
Missouri Agricultural
Experiment Station

Soil survey of Clinton County Missouri



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soil survey of
Clinton County, Missouri

By Paul E. Minor and Keith O. Davis, Soil Conservation Service

Fieldwork by Paul E. Minor and Keith O. Davis, Soil Conservation Service

United States Department of Agriculture, Soil Conservation Service
in cooperation with the Missouri Agricultural Experiment Station

CLINTON COUNTY is in the northwestern part of Missouri. Plattsburg, the county seat, is 25 miles southeast of St. Joseph and 30 miles north of Kansas City. In 1970, the population of the county was 12,462. The population of Plattsburg was 1,832. The county takes in an area of 268,800 acres, or 420 square miles.

Farming is the main enterprise in Clinton County. The main crops are corn, soybeans, sorghum, legumes, and grasses. Raising beef cattle is the largest livestock enterprise. Hogs, dairy cattle, and sheep are also raised.

general nature of the county

In this section, climate; physiography, relief, and drainage; history and development; and farming are discussed.

climate

Prepared by the National Climatic Center, Asheville, North Carolina.

Clinton County consistently has cold winters and long, hot summers. Heavy rains occur mainly in spring and early in summer, when moist air from the Gulf of Mexico interacts with drier continental air. The annual rainfall normally is adequate for corn, soybeans, and all grain crops.

Table 1 gives data on temperature and precipitation for the survey area as recorded at St. Joseph, Missouri, in the period 1952 to 1979. Table 2 shows probable dates of the first freeze in fall and the last freeze in spring. Table 3 provides data on length of the growing season.

In winter the average temperature is 29 degrees F, and the average daily minimum temperature is 19 degrees. The lowest temperature on record, which occurred at St. Joseph on January 12, 1974, is -25 degrees. In summer the average temperature is 76 degrees, and the average daily maximum temperature is 87 degrees. The highest recorded temperature, which occurred on July 13, 1954, is 107 degrees.

Growing degree days are shown in table 1. They are equivalent to "heat units." During the month, growing degree days accumulate by the amount that the average temperature each day exceeds a base temperature (50 degrees F). The normal monthly accumulation is used to schedule single or successive plantings of a crop between the last freeze in spring and the first freeze in fall.

The total annual precipitation is 34 inches. Of this, 24 inches, or 70 percent, usually falls in April through September, which includes the growing season for most crops. In 2 years out of 10, the rainfall in April through September is less than 19 inches. The heaviest 1-day rainfall during the period of record was 5.88 inches at St. Joseph on May 19, 1962. Thunderstorms occur on about 55 days each year, and most occur in summer.

The average seasonal snowfall is 21 inches. The greatest snow depth at any one time during the period of record was 18 inches. On the average, 10 days have at least 1 inch of snow on the ground. The number of such days varies greatly from year to year.

The average relative humidity in midafternoon is about 60 percent. Humidity is higher at night, and the average at dawn is about 80 percent. The sun shines 70 percent of the time possible in summer and 50 percent in winter.

TABLE 15.--PHYSICAL AND CHEMICAL PROPERTIES OF THE SOILS

[The symbol < means less than. Entries under "Erosion factors--T" apply to the entire profile. Entries under "Wind erodibility group" and "Organic Matter" apply only to the surface layer. Absence of an entry indicates that data were not available or were not estimated]

Soil name and map symbol	Depth	Clay	Moist bulk density	Permeability	Available water capacity	Soil reaction	Shrink-swell potential	Erosion factors K	Erosion factors T	Wind erodibility group	Organic matter
	In	Pct	G/cm³	In/hr	In/in	pH					Pct
1B, 1C------------ Marshall	0-9	25-27	1.25-1.30	0.6-2.0	0.21-0.23	5.6-7.3	Low-----------	0.32	5	6	3-4
	9-72	27-34	1.30-1.35	0.6-2.0	0.18-0.20	5.6-7.3	Moderate------	0.43			
5C2--------------- Clinton	0-6	15-26	1.30-1.40	0.6-2.0	0.20-0.22	5.6-7.3	Low-----------	0.37	5	6	1-2
	6-43	36-42	1.35-1.45	0.2-0.6	0.16-0.20	5.1-6.0	Moderate------	0.37			
	43-74	24-35	1.40-1.55	0.6-2.0	0.18-0.20	6.1-6.5	Moderate------	0.37			
7B, 7C------------ Sharpsburg	0-16	27-34	1.30-1.35	0.6-2.0	0.21-0.23	5.1-7.3	Moderate------	0.32	5	7	3-4
	16-53	36-42	1.35-1.40	0.2-0.6	0.18-0.20	5.1-6.0	Moderate------	0.43			
	53-75	28-32	1.40-1.45	0.6-2.0	0.18-0.20	6.1-6.5	Moderate------	0.43			
8C---------------- Higginsville	0-9	22-30	1.30-1.50	0.6-2.0	0.21-0.24	5.6-7.3	Low-----------	0.37	4	6	3-4
	9-41	27-35	1.40-1.50	0.6-2.0	0.14-0.19	5.1-6.5	Moderate------	0.37			
	41-66	27-33	1.50-1.60	0.6-2.0	0.14-0.19	5.1-6.5	Moderate------	0.37			
13---------------- Haig	0-10	22-27	1.35-1.40	0.6-2.0	0.22-0.24	5.6-7.3	Moderate------	0.37	5	6	3-4
	10-15	28-48	1.30-1.35	0.6-2.0	0.21-0.23	5.1-6.0	High----------	0.37			
	15-45	40-50	1.30-1.45	0.06-0.2	0.12-0.14	5.1-7.3	High----------	0.37			
	45-72	25-40	1.40-1.50	0.2-0.6	0.18-0.20	6.1-7.3	High----------	0.37			
14B--------------- Grundy	0-9	12-27	1.35-1.50	0.6-2.0	0.22-0.24	5.6-7.3	Moderate------	0.37	3	6	3-4
	9-16	32-45	1.35-1.45	0.2-0.6	0.18-0.20	5.6-6.5	High----------	0.37			
	16-36	40-50	1.30-1.40	0.06-0.2	0.11-0.13	5.1-7.3	High----------	0.37			
	36-74	29-35	1.35-1.40	0.06-0.2	0.18-0.20	5.6-7.3	High----------	0.37			
14B2-------------- Grundy	0-7	28-32	1.35-1.45	0.2-0.6	0.18-0.20	5.6-7.3	High----------	0.37	2	6	2-3
	7-35	32-45	1.35-1.45	0.2-0.6	0.18-0.20	5.6-6.5	High----------	0.37			
	35-46	40-50	1.30-1.40	0.06-0.2	0.11-0.13	5.1-7.3	High----------	0.37			
	46-60	29-35	1.35-1.40	0.06-0.2	0.18-0.20	5.6-7.3	High----------	0.37			
14C--------------- Grundy	0-9	12-27	1.35-1.50	0.6-2.0	0.22-0.24	5.6-7.3	Moderate------	0.37	3	6	3-4
	9-16	32-45	1.35-1.45	0.2-0.6	0.18-0.20	5.6-6.5	High----------	0.37			
	16-36	40-50	1.30-1.40	0.06-0.2	0.11-0.13	5.1-7.3	High----------	0.37			
	36-74	28-35	1.35-1.40	0.06-0.2	0.18-0.20	5.6-7.3	High----------	0.37			
14C2-------------- Grundy	0-7	28-32	1.35-1.45	0.2-0.6	0.18-0.20	5.6-7.3	High----------	0.37	2	6	2-3
	7-35	32-45	1.35-1.45	0.2-0.6	0.18-0.20	5.6-6.5	High----------	0.37			
	35-46	40-50	1.30-1.40	0.06-0.2	0.11-0.13	5.1-7.3	High----------	0.37			
	46-60	29-35	1.35-1.40	0.06-0.2	0.18-0.20	5.6-7.3	High----------	0.37			
16B, 16C---------- Ladoga	0-7	18-27	1.30-1.35	0.6-2.0	0.22-0.24	5.6-7.3	Low-----------	0.32	5	6	2-3
	7-40	36-42	1.30-1.40	0.2-0.6	0.18-0.20	5.1-6.0	Moderate------	0.43			
	40-65	24-32	1.35-1.45	0.6-2.0	0.18-0.20	5.1-6.5	Moderate------	0.43			
22---------------- Wiota	0-13	24-32	1.30-1.35	0.6-2.0	0.21-0.23	5.6-7.3	Moderate------	0.32	5	7	3-4
	13-60	30-36	1.30-1.40	0.6-2.0	0.18-0.20	5.1-6.5	Moderate------	0.43			
23---------------- Bremer	0-17	25-32	1.25-1.30	0.6-2.0	0.21-0.23	5.6-7.3	Moderate------	0.28	5	7	5-7
	17-42	35-42	1.30-1.40	0.2-0.6	0.15-0.17	5.6-6.5	High----------	0.28			
	42-66	32-38	1.40-1.45	0.2-0.6	0.18-0.20	5.6-7.3	High----------	0.28			
24---------------- Nevin	0-18	26-29	1.30-1.35	0.6-2.0	0.21-0.23	5.6-7.3	Moderate------	0.32	5	7	4-6
	18-65	30-35	1.30-1.40	0.6-2.0	0.18-0.20	5.6-7.3	Moderate------	0.43			
25D--------------- Vanmeter	0-6	13-24	1.30-1.40	0.2-0.6	0.18-0.20	6.6-8.4	Low-----------	0.43	3	6	1-2
	6-34	40-60	1.50-1.60	<0.06	0.12-0.14	7.4-8.4	High----------	0.32			
	34-50	40-75	1.70-1.90	<0.06	0.08-0.10	7.4-8.4	High----------	----			

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TABLE 15.--PHYSICAL AND CHEMICAL PROPERTIES OF THE SOILS--Continued

Soil name and map symbol	Depth	Clay	Moist bulk density	Permeability	Available water capacity	Soil reaction	Shrink-swell potential	Erosion factors		Wind erodibility group	Organic matter
								K	T		
	In	Pct	G/cm^3	In/hr	In/in	pH					Pct
29F:											
Vanmeter	0-7	27-34	1.30-1.40	0.2-0.6	0.14-0.16	6.6-8.4	Moderate	0.43	2	4	1-2
	7-36	40-60	1.50-1.60	<0.06	0.12-0.14	7.4-8.4	High	0.32			
	36-57	40-75	1.70-1.90	<0.06	0.08-0.10	7.4-8.4	High	----			
Gasconade	0-4	35-50	1.30-1.45	0.6-2.0	0.12-0.15	6.1-7.8	Moderate	0.32	2	7	2-4
	4-18	40-60	1.45-1.70	0.2-0.6	0.05-0.07	6.1-7.8	Moderate	0.20			
	18	---	---	---	---	---	------------	----			
33C Armstrong	0-8	22-27	1.45-1.50	0.6-2.0	0.20-0.22	5.6-7.3	Moderate	0.32	3	6	2-3
	8-41	36-48	1.45-1.55	0.06-0.2	0.11-0.16	4.5-6.5	High	0.32			
	41-72	30-36	1.55-1.75	0.2-0.6	0.14-0.16	5.1-7.3	Moderate	0.32			
33D Armstrong	0-6	27-38	1.45-1.50	0.2-0.6	0.18-0.20	5.6-7.3	Moderate	0.32	3	6	2-3
	6-72	36-48	1.45-1.55	0.06-0.2	0.11-0.16	4.5-7.3	High	0.32			
34C3, 34D3 Armstrong	0-5	27-38	1.45-1.50	0.2-0.6	0.18-0.20	5.6-7.3	Moderate	0.32	2	6	1-2
	5-72	36-48	1.45-1.55	0.06-0.2	0.11-0.16	4.5-7.3	High	0.32			
37D, 37E Gara	0-10	24-27	1.50-1.55	0.6-2.0	0.20-0.22	5.1-7.3	Moderate	0.28	5	6	2-3
	10-36	30-38	1.55-1.75	0.2-0.6	0.15-0.19	4.1-6.5	Moderate	0.28			
	36-60	24-38	1.75-1.85	0.2-0.6	0.16-0.18	6.6-7.8	Moderate	0.37			
39C2 Clarinda	0-9	30-38	1.45-1.50	0.2-0.6	0.17-0.19	5.1-7.3	Moderate	0.37	3	7	2-3
	9-38	40-60	1.45-1.60	<0.06	0.14-0.16	5.1-7.8	High	0.37			
	38-64	40-60	1.55-1.75	<0.06	0.14-0.16	5.6-7.8	High	0.37			
2C Lamoni	0-16	27-38	1.45-1.50	0.2-0.6	0.17-0.21	5.1-7.3	Moderate	0.32	2	7	3-4
	16-44	38-50	1.55-1.75	0.06-0.2	0.13-0.17	5.1-7.8	High	0.32			
	44-60	32-40	1.75-1.85	0.06-0.2	0.14-0.18	6.1-7.8	High	0.32			
2C2 Lamoni	0-6	27-38	1.45-1.50	0.2-0.6	0.17-0.21	5.1-7.3	Moderate	0.32	2	7	2-3
	6-72	38-50	1.55-1.75	0.06-0.2	0.13-0.17	5.1-7.8	High	0.32			
2D Lamoni	0-16	27-38	1.45-1.50	0.2-0.6	0.17-0.21	5.1-7.3	Moderate	0.32	2	7	3-4
	16-44	38-50	1.55-1.75	0.06-0.2	0.13-0.17	5.1-7.3	High	0.32			
	44-60	32-40	1.75-1.85	0.06-0.2	0.14-0.18	6.1-7.8	High	0.32			
4D Shelby	0-11	24-27	1.50-1.55	0.6-2.0	0.20-0.22	5.6-7.3	Moderate	0.28	5	6	3-4
	11-32	30-35	1.55-1.75	0.2-0.6	0.16-0.18	5.6-7.8	Moderate	0.28			
	32-60	30-35	1.75-1.85	0.2-0.6	0.16-0.18	6.6-8.4	Moderate	0.37			
2 Kennebec	0-40	22-30	1.25-1.35	0.6-2.0	0.22-0.24	5.6-7.3	Moderate	0.32	5	6	4-6
	40-63	24-28	1.35-1.40	0.6-2.0	0.20-0.22	6.1-7.3	Moderate	0.43			
5B Colo	0-10	27-32	1.28-1.32	0.6-2.0	0.21-0.23	5.6-7.3	High	0.28	5	7	5-7
	10-72	30-35	1.25-1.35	0.6-2.0	0.18-0.20	6.1-7.3	High	0.28			
1 Nodaway	0-65	18-28	1.25-1.35	0.6-2.0	0.20-0.23	6.1-7.3	Moderate	0.37	5	6	2-3
9. Pits											

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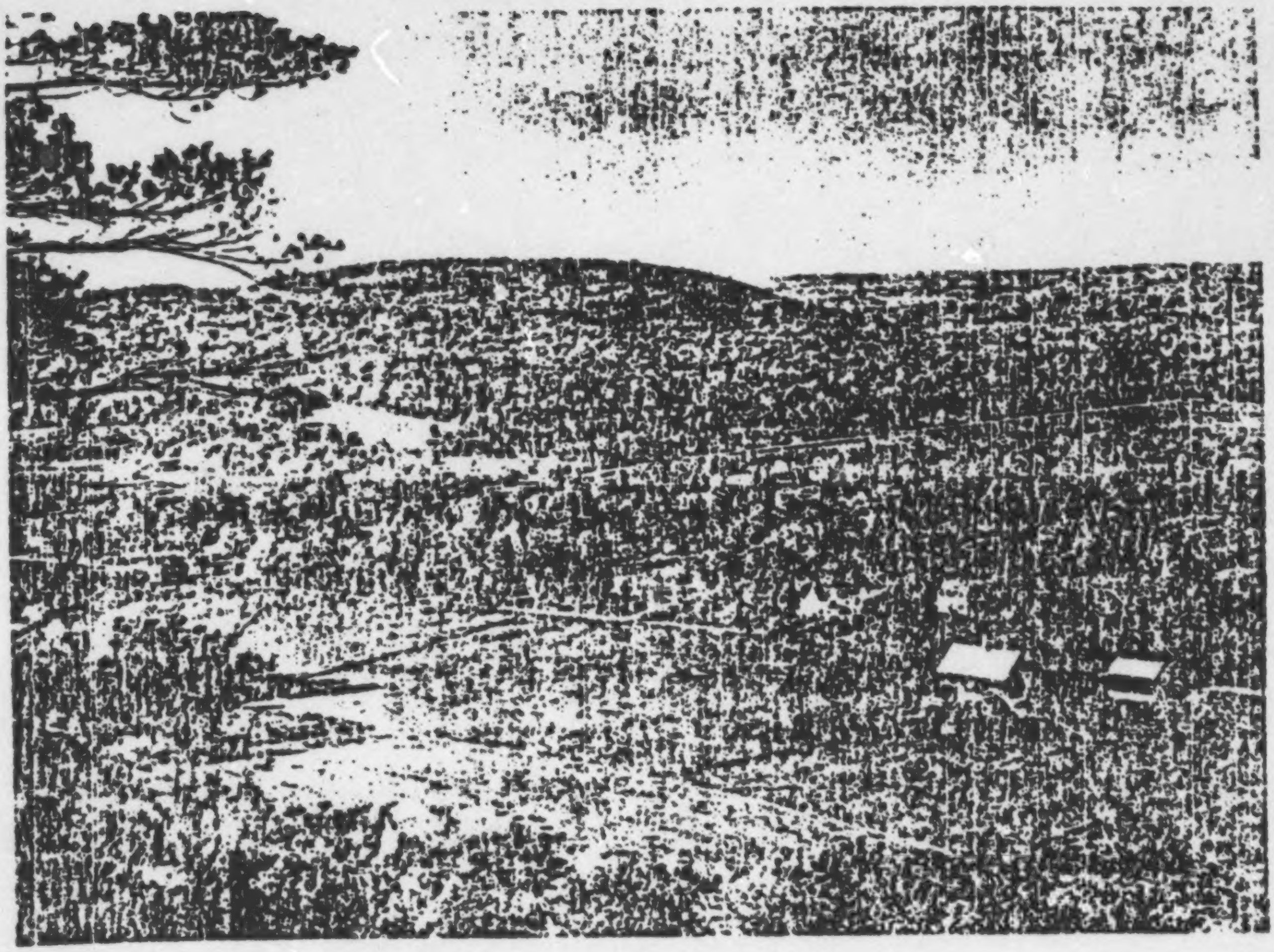
SOIL SURVEY OF

Franklin County, Vermont



United States Department of Agriculture
Soil Conservation Service
in cooperation with the
Vermont Agricultural Experiment Station and the
Vermont Agency of Environmental Conservation

SOIL SURVEY OF FRANKLIN COUNTY, VERMONT

By Dennis J. Flynn and Robert V. Joslin, Soil Conservation Service

Fieldwork by Dennis J. Flynn, Robert V. Joslin, John A. Pratt,
and Carl T. Britt, Soil Conservation Service, and John Doles, Edward White,
Henry Ferguson, and Drew Adam, Vermont Agency of Environmental Conservation

United States Department of Agriculture, Soil Conservation Service,
in cooperation with the Vermont Agricultural Experiment Station and the
Vermont Agency of Environmental Conservation

FRANKLIN COUNTY is in the northwest corner of Vermont. The county is 421,760 acres, or 659 square miles. St. Albans, the largest city and county seat, is in the southwestern part of the county, near Lake Champlain. About 50 percent of the county is in woodland; 45 percent is in farms; and 5 percent is urbanized, is used for recreation, or is idle. The farms are mainly in the Champlain Valley and the major river valleys. Small family farms are being replaced by larger corporate farms or are being subdivided and sold as second homes. The manufacture of packaging materials and the shipment of bulk milk are major industries in the county.

General nature of the area

This section provides general information about Franklin County. It briefly discusses settlement and population, farming, transportation, and climate and describes the physiography, geology, and drainage of the county.

Settlement and population

What is considered the first settlement in Vermont was made in the early 1600's in Franklin County when the St. Francis Indians, a part of the Abenaki Tribe of Maine, settled at Swanton, along the banks of the Missisquoi River. Though the French mapped and deeded the areas, the first settlers to take up permanent residence in the county were from Massachusetts. St. Albans was chartered in 1763, and Franklin County was organized 1792.

The population of Franklin County grew steadily from the 1700's to about 1900. Farming and the influx of small light industry, especially in Enosburg Falls, Sheldon, and St. Albans, were the major reasons for the increase. From 1900 to 1965, however, the population steadily declined. The demise of the small farm and the development of the large industrial complex in the Midwest and along the East Coast accounted for much of the loss in population. Since 1965, the population of Franklin County has increased. The resurgence of the small farm, the purchase of second homes by city dwellers, and the return of light industry are the main reasons for the increase.

Farming

Farming is the main source of income in Franklin County. The county is a major producer of maple products and milk, and it is a major supplier for the State and the New England region.

In the 18th century Franklin County was a major source of grain for feed and food for Vermont and the Northeast. Later, the farmers began raising beef cattle and sheep. In the mid-1800's the dairy industry was established in the county.

Franklin County farmers raise hay and silage corn as feed for their dairy cattle. Grain for feed, fertilizer and herbicides for crops, and fuel for farm equipment are imported. The average size of the dairy herds in Franklin County increased from 28.6 cows in 1953 to 60.1 cows in 1974. The number of dairy herds in production decreased from 1,405 in 1953 to 662 in 1974 (*6*).

Transportation

The major highway in Franklin County is Interstate 89, which passes north-south through the county and links the area with Montreal to the north and Burlington, Vermont, and Boston, Massachusetts, to the south. Other highways in the counties are U.S. route 7 and Vermont routes 104, 105, 108, 36, and 78. Commerical carriers provide bus service along the major highways in the county.

Private air transportation facilities are available at Franklin County State Airport, at Swanton, Vermont. Commercial air service is available outside the county at Burlington International Airport in Burlington, Vermont, or at Dorval or Maribel International Airports in Montreal, Canada.

Daily passenger rail service is provided at St. Albans and links the county to all the major passenger rail lines in the United States. Freight service is provided by three railroads that cross the county.

TABLE 16.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS

[The symbol < means less than; > means greater than. The erosion tolerance factor (T) is for the entire profile. Absence of an entry means data were not available or were not estimated]

Soil name and map symbol	Depth	Permea-bility	Available water capacity	Soil reaction	Shrink-swell potential	Risk of corrosion		Erosion factors	
						Uncoated steel	Concrete	K	T
	In	In/hr	In/in	pH					
AuA----------------- Au Gres	0-9	6.0-20	0.07-0.10	4.5-7.3	Very low-----	Low--------	Moderate	0.15	5
	9-22	6.0-20	0.06-0.09	4.5-7.3	Very low-----	Low--------	Moderate	0.15	
	22-60	>20	0.05-0.07	5.1-6.0	Very low-----	Low--------	Moderate	0.15	
BeB, BeC------------ Belgrade	0-5	0.6-2.0	0.17-0.30	5.1-6.5	Low-----------	Moderate	Moderate	0.49	3
	5-22	0.6-2.0	0.15-0.26	5.1-6.5	Low-----------	Moderate	Moderate	0.64	
	22-60	0.06-2.0	0.15-0.26	5.1-6.5	Low-----------	Moderate	Moderate	0.64	
Bg------------------ Binghamville	0-11	0.6-2.0	0.20-0.25	5.6-7.3	Low-----------	High------	Moderate	0.49	3
	11-27	0.2-2.0	0.18-0.22	5.1-7.3	Low-----------	High------	Moderate	0.49	
	27-60	0.06-0.2	0.18-0.22	5.6-7.3	Low-----------	High------	Moderate	0.49	
Br------------------ Birdsall	0-5	0.2-2.0	0.17-0.30	4.5-6.0	Low-----------	High------	High------	0.49	3
	5-21	0.2-0.6	0.15-0.26	5.1-7.3	Low-----------	High------	High------	0.49	
	21-60	0.06-0.2	0.15-0.26	5.1-7.3	Low-----------	High------	High------	0.49	
BxC, BxD, BxE------ Buxton	0-9	0.2-2.0	0.14-0.22	4.5-6.5	Low-----------	High------	Moderate	0.28	3
	9-31	0.2-0.6	0.11-0.21	4.5-6.5	Low-----------	High------	Moderate	0.49	
	31-60	<0.2	0.09-0.21	5.6-7.3	Moderate-----	High------	Moderate	0.49	
CaA, CaB------------ Cabot	0-7	0.6-2.0	0.18-0.22	5.1-7.3	Low-----------	High------	Low--------	0.28	3
	7-16	0.6-2.0	0.16-0.20	5.6-7.3	Low-----------	High------	Low--------	0.28	
	16-60	<0.2	0.05-0.12	5.6-7.3	Low-----------	High------	Low--------	0.28	
CbA, CbB------------ Cabot	0-7	0.6-2.0	0.14-0.20	5.1-7.3	Low-----------	High------	Low--------	0.28	3
	7-16	0.6-2.0	0.16-0.20	5.6-7.3	Low-----------	High------	Low--------	0.28	
	16-60	<0.2	0.05-0.12	5.6-7.3	Low-----------	High------	Low--------	0.28	
Ce------------------ Carlisle	0-60	0.2-6.0	0.35-0.45	5.6-7.3	-------------	High------	Low--------	---	---
CoB, CoC, CoD, CoE- Colton	0-7	>6.0	0.03-0.07	4.5-5.0	Low-----------	Low--------	High------	0.17	3
	7-25	>6.0	0.02-0.05	4.5-5.0	Low-----------	Low--------	High------	0.17	
	25-60	>20	0.01-0.02	4.5-5.0	Low-----------	Low--------	High------	0.17	
CpB----------------- Copake	0-8	0.6-6.0	0.11-0.18	4.5-6.5	Low-----------	Low--------	Moderate	0.32	3
	8-21	0.6-6.0	0.08-0.18	4.5-7.3	Low-----------	Low--------	Moderate	0.24	
	21-60	>20	0.01-0.05	6.6-8.4	Low-----------	Low--------	Low--------	0.17	
Cv------------------ Covington	0-6	<0.2	0.14-0.16	5.6-7.3	High----------	High------	Moderate	0.49	3
	6-32	<0.06	0.12-0.14	5.6-7.8	High----------	High------	Moderate	0.49	
	32-60	<0.06	0.12-0.14	6.6-8.4	High----------	High------	Low--------	0.49	
DeB, DeC------------ Deerfield	0-8	6.0-20	0.07-0.13	4.5-6.0	Low-----------	Low--------	High------	0.17	5
	8-18	6.0-20	0.01-0.13	4.5-6.0	Low-----------	Low--------	High------	0.15	
	18-60	>20	0.01-0.08	4.5-6.0	Low-----------	Low--------	High------	0.15	
EdA, EdB, EdC------ Eldridge	0-7	6.0-20	0.08-0.16	5.1-6.5	Low-----------	Moderate	Moderate	0.32	3
	7-28	6.0-20	0.04-0.11	5.1-6.5	Low-----------	Moderate	Moderate	0.32	
	28-60	0.2-0.6	0.13-0.22	5.1-7.3	Low-----------	Moderate	Low--------	0.43	
EnA, EnB------------ Enosburg	0-7	6.0-20	0.10-0.18	4.5-6.5	Low-----------	High------	Moderate	0.32	3
	7-22	6.0-20	0.04-0.08	4.5-7.3	Low-----------	High------	Moderate	0.32	
	22-60	0.2-0.6	0.13-0.22	6.1-7.3	Low-----------	High------	Low--------	0.43	
FaB, FaC------------ Farmington	0-4	0.6-2.0	0.11-0.19	5.1-6.5	Low-----------	Low--------	Moderate	0.32	2
	4-14	0.6-2.0	0.07-0.18	5.6-7.3	Low-----------	Low--------	Moderate	0.28	
	14	---	---	---	-------------	----------	----------	---	
[1]FmC, [1]FmD: Farmington--------	0-4	0.6-2.0	0.11-0.19	5.1-6.5	Low-----------	Low--------	Moderate	0.32	2
	4-14	0.6-2.0	0.07-0.18	5.6-7.3	Low-----------	Low--------	Moderate	0.28	
	14	---	---	---	-------------	----------	----------	---	

See footnote at end of table.

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TABLE 16.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS--Continued

Soil name and map symbol	Depth	Permeability	Available water capacity	Soil reaction	Shrink-swell potential	Risk of corrosion		Erosion factors	
						Uncoated steel	Concrete	K	T
	In	In/hr	In/in	pH					
[1]FmC, [1]FmD: Rock outcrop.									
GeA, GeB, GeC------ Georgia	0-2	0.6-2.0	0.13-0.20	5.6-7.3	Low-----------	Moderate	Low-------	0.43	3
	2-22	0.6-2.0	0.08-0.19	5.6-7.3	Low-----------	Moderate	Low-------	0.32	
	22-60	0.06-0.2	0.08-0.19	6.1-7.3	Low-----------	Moderate	Low-------	0.32	
GrB, GrC----------- Georgia	0-2	0.6-2.0	0.08-0.16	5.6-7.3	Low-----------	Moderate	Low-------	0.32	3
	2-22	0.6-2.0	0.08-0.19	5.6-7.3	Low-----------	Moderate	Low-------	0.32	
	22-60	0.06-0.2	0.08-0.19	6.1-7.3	Low-----------	Moderate	Low-------	0.32	
Ha----------------- Hadley	0-8	0.6-2.0	0.15-0.25	4.5-7.3	Low-----------	Low-------	Moderate	0.49	3
	8-32	0.6-6.0	0.13-0.20	4.5-7.8	Low-----------	Low-------	Moderate	0.49	
	32-60	0.6-6.0	0.10-0.20	5.6-7.3	Low-----------	Low-------	Moderate	0.49	
HbA, HbB, HbC, HbD, HbE-------------- Hinesburg	0-7	6.0-20	0.08-0.12	5.6-6.5	Low-----------	Low-------	Moderate	0.17	3
	7-22	6.0-20	0.04-0.10	5.6-6.5	Low-----------	Low-------	Moderate	0.20	
	22-60	0.2-0.6	0.15-0.22	5.1-7.3	Low-----------	Low-------	Low-------	0.43	
KbA, KbB----------- Kingsbury	0-6	0.06-0.2	0.12-0.22	5.1-6.5	High----------	High------	Moderate	0.49	3
	6-36	<0.06	0.12-0.13	5.1-7.3	High----------	High------	Low-------	0.28	
	36-60	<0.06	0.12-0.14	6.6-8.4	High----------	High------	Low-------	0.28	
Le----------------- Limerick	0-8	0.6-2.0	0.18-0.25	5.1-7.3	Low-----------	High------	Low-------	0.20	3
	8-18	0.6-2.0	0.18-0.25	5.6-7.3	Low-----------	High------	Low-------	0.20	
	18-60	0.6-2.0	0.18-0.25	5.6-7.3	Low-----------	High------	Low-------	0.20	
LoB, LoC, LoD------ Lordstown	0-9	0.6-2.0	0.11-0.17	4.5-5.5	Low-----------	Low-------	High------	0.20	3
	9-27	0.6-2.0	0.10-0.16	4.5-5.5	Low-----------	Low-------	High------	0.28	
	27	---	---	---	-------------	---------	---------	---	
[1]LrC, [1]LrD, [1]LrE: Lordstown--------	0-9	0.6-2.0	0.11-0.17	4.5-5.5	Low-----------	Low-------	High------	0.20	3
	9-27	0.6-2.0	0.10-0.16	4.5-5.5	Low-----------	Low-------	High------	[illegible]	
	27	---	---	---	-------------	---------	---------	---	
Rock outcrop.									
Ly----------------- Lyons	0-9	0.6-2.0	0.15-0.20	5.6-7.3	Low-----------	High------	Low-------	---	---
	9-31	0.2-2.0	0.08-0.18	6.1-7.3	Low-----------	High------	Low-------	---	
	31-60	<0.2	0.06-0.15	7.4-8.4	Low-----------	High------	Low-------	---	
Ma. Marsh									
MeA, MeB----------- Massena	0-8	0.6-2.0	0.14-0.20	5.6-7.3	Low-----------	Moderate	Moderate	0.28	3
	8-25	0.06-0.6	0.08-0.15	5.6-7.3	Low-----------	Moderate	Moderate	[illegible]	
	25-44	0.06-0.6	0.06-0.14	6.6-7.8	Low-----------	Moderate	Low-------	[illegible]	
MnA---------------- Massena	0-8	0.6-2.0	0.12-0.18	5.6-7.3	Low-----------	Moderate	Moderate	0.17	3
	8-25	0.06-0.6	0.08-0.15	5.6-7.3	Low-----------	Moderate	Moderate	0.28	
	25-44	0.06-0.6	0.06-0.14	6.6-7.8	Low-----------	Moderate	Low-------	0.28	
MsA, MsB, MsC, MsD, MsE-------------- Missisquoi	0-5	6.0-20	0.04-0.08	5.1-6.5	Low-----------	Low-------	High------	0.17	2
	5-12	6.0-20	0.02-0.12	5.1-6.5	Low-----------	Low-------	High------	[illegible]	
	12-35	6.0-20	0.03-0.07	5.1-6.5	Low-----------	Low-------	High------	[illegible]	
	35-60	6.0-20	0.02-0.03	6.1-7.8	Low-----------	Low-------	Moderate	0.17	
MuB, MuC----------- Munson	0-8	0.6-2.0	0.16-0.25	5.6-6.5	Low-----------	High------	Low-------	0.49	3
	8-14	0.2-2.0	0.14-0.22	5.6-6.5	Low-----------	High------	Low-------	0.49	
	14-40	<0.2	0.14-0.20	5.6-7.3	Moderate-----	High------	Low-------	0.49	
Od----------------- Ondawa Variant	0-7	0.6-2.0	0.18-0.22	5.6-7.3	Low-----------	Low-------	Low-------	---	---
	7-27	0.6-2.0	0.16-0.21	5.6-7.3	Low-----------	Low-------	Low-------	---	
	27-60	6.0-20	0.01-0.10	5.7-7.3	Low-----------	Low-------	Low-------	---	

See footnote at end of table.

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SOIL SURVEY OF

Clark County, Washington

United States Department of Agriculture
Soil Conservation Service
In cooperation with
Washington Agricultural Experiment Station

Issued November 1972

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33.

SOIL SURVEY OF CLARK COUNTY, WASHINGTON

BY DALE A. McGEE, SOIL CONSERVATION SERVICE

SOILS SURVEYED BY DALE A. McGEE, RUDOLPH W. MAYKO, WILLARD A. CALL, CARL J. McMURPHY, AND JOHN G. KRAUTSCHEID, SOIL CONSERVATION SERVICE.

UNITED STATES DEPARTMENT OF AGRICULTURE, IN COOPERATION WITH THE WASHINGTON AGRICULTURAL EXPERIMENT STATION

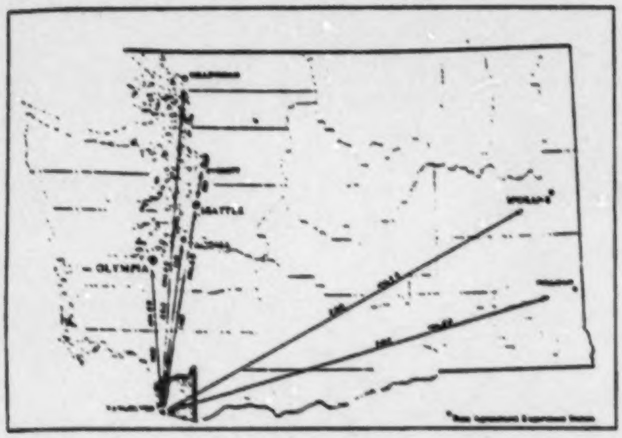

Figure 1.—Location of Clark County in Washington.

CLARK COUNTY is in the southwestern part of the State of Washington (fig. 1). The Columbia River forms its southern and western borders. It is bounded on the north by the Lewis River and on the east by Skamania County.

The land area comprises about 400,000 acres, or about 630 square miles. The population is approximately 101,000. The largest city, Vancouver, population 34,500, is the county seat and is 100 miles south of Olympia, the State capital. Vancouver is along the north shore of the Columbia River, opposite Portland, Oregon.

Economic development in Clark County is diversified. Farming is important, but it is secondary in value of total products to industrial products, which include lumber, pulp, paper, aluminum, carborundum, and chemicals. About 42 percent of the county is cleared and in farmland; the rest is forested or logged-off land. Most of the farmland lies in the central, western, and southwestern parts of the county. This area is composed of terraces and terrace plains, about 30 to 800 feet above sea level. The northern and eastern parts of the county are forested foothills and mountains of the Cascade Range. In these areas farming is confined to the larger valleys. Much of the cleared land is in hay and pasture.

Dairying is the most important farm enterprise in the county; it accounts for more than 40 percent of the value of farm products sold. Ranking second and third are livestock and poultry. Other important farm products are vegetables, berries, and orchard fruits.

The county lies in a long structural basin (Willamette-Puget Trough) between the Pacific Coast ranges to the west and the parallel Cascade Range to the east. The Columbia River, the major trunk stream of the Pacific Northwest, flows through the Cascade Range, borders Clark County as it crosses the trough, then passes through the Pacific Coast ranges into the Pacific Ocean to the west.

The western part of the county consists of a series of gently rolling alluvial terraces that form plains and benches rising steplike from the present level of the Columbia River. The elevations in these areas range from a few feet to more than 800 feet above sea level. The eastern part of the county consists of high old alluvial terraces against volcanic foothills and mountains of the western slopes of the Cascade Range. Along the eastern margin of the county, some of the higher peaks rise to an elevation of nearly 4,000 feet. Mountain ridges 2,000 to 3,000 feet in elevation are common. Much of this area is very steep, and a fall of 1,000 feet within a lateral distance of half a mile is not uncommon. The mountainous terrain is heavily dissected by streams that originate in this area and to the east. Most of the important streams that drain the county flow in a westerly direction. The more prominent streams are: the North Fork of the Lewis River; the East Fork of the Lewis River; the Washougal and Little Washougal Rivers; and Lacamas, Salmon, Big Tree, Cedar, Canyon, Mason, and Lockwood Creeks.

How This Survey Was Made

Soil scientists made this survey to learn what kinds of soil are in Clark County, where they are located, and how they can be used. The soil scientists went into the county knowing they likely would find many soils they had already seen and perhaps some they had not. They observed the steepness, length, and shape of slopes, the

TABLE 7.—*Estimated physical and chemical properties of the soils*

Soil series and map symbols	Depth from surface	Classification			Percentage passing sieve—			Permeability	Available water capacity	I ac
		Dominant USDA texture	Unified	AASHO	No. 4 (4.76 mm.)[1]	No. 10 (2.0 mm.)	No. 200 (0.074 mm.)			
	Inches							*Inches per hour*	*Inches per inch of soil*	*p.*
Bear Prairie: BpB, BpC.	0-31	Silt loam	CL	A-6	90-100	85-95	75-85	0. 63-2. 0	0. 19-0. 21	4. 6
	51-75	Gravelly loam	ML	A-4	70-80	65-75	50-60	0. 63-2. 0	0. 14-0. 16	5. 1
Cinebar: CnB, CnD, CnE, CnG.	0-65	Silt loam and loam.	ML	A-4	90-100	85-95	60-70	0. 63-2. 0	0. 19-0. 21	5. 1
CrE, CrG.	0-60	Silt loam	CL	A-4	70-80	60-80	50-70	0. 63-2. 0	0. 12-0. 14	5. 1
Cispus: CsF.	0-24	Gravelly sandy loam.	SM	A-2	70-80	65-75	20-30	2. 0-6. 3	0. 08-0. 10	5. 6-
	24-53	Very cobbly sand	SM	A-1	35-50	30-50	5-10	>20. 0	0. 03-0. 05	5. 6-
Cloquato: CtA.	0-40	Silt loam	ML	A-4	--------	100	70-80	0. 63-0. 20	0. 19-0. 21	5. 6-
	40-72	Sandy loam and sand.	SM	A-2	100	95-100	15-30	>6. 3	0. 08-0. 10	5. 6-
Cove: CvA.	0-36	Clay	CH	A-7	--------	100	70-80	<0. 06	0. 11-0. 16	5. 6-
	36-54	Gravelly silty clay loam.	CL	A-7	65-75	60-70	50-60	0. 06-0. 20	0. 15-0. 17	5. 6-
Cove, thin solum: CwA.	0-14	Silty clay loam	CL	A-7	--------	100	85-95	0. 06-0. 20	0. 19-0. 21	4. 5-
	14-21	Clay	CH	A-7	--------	100	70-80	<0. 06	0. 14-0. 16	5. 6-
	21-60	Silt loam	ML or CL	A-4 or A-6.	--------	100	65-75	0. 06-0. 20	0. 19-0. 21	6. 6-
Dollar: DoB.	0-32	Loam	ML	A-4	100	90-95	60-70	0. 63-2. 0	0. 16-0. 18	4. 5-
	32-60	Loam (fragipan)	ML or CL	A-4	100	95-100	60-70	<0. 06	0. 06-0. 08	4. 5-
Fill land: Fn.	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Gee: GeB, GeD, GeE, GeF.	0-22	Silt loam	ML or CL	A-6	--------	100	70-85	0. 63-2. 0	0. 19-0. 21	5. 1-
	22-72	Silty clay loam	CL	A-6	--------	100	70-80	<0. 06	0. 06-0. 08	5. 1-
Gumboot: GuB.	0-12	Silt loam	OL	A-7	90-95	85-95	75-85	0. 63-2. 0	0. 19-0. 21	4. 5-
	12-50	Gravelly silty clay loam, clay loam.	CL	A-6	90-100	85-95	65-75	0. 06-0. 2	0. 19-0. 21	6. 1-
	50-60	Very gravelly silty clay.	GC	A-7	40-50	35-50	25-35	<0. 06	0. 06-0. 08	6. 1-
Hesson: HcB, HcD, HcE, HcF.	0-22	Clay loam	CL	A-7	85-95	85-95	65-75	0. 63-2. 0	0. 19-0. 21	4. 5-
	22-91	Clay	CH	A-7	85-90	85-90	75-85	0. 2-0. 63	0. 14-0. 16	4. 5-
HgB, HgD, HhE.	0-22	Gravelly clay loam.	SC	A-6	75-85	70-80	40-50	0. 63-2. 0	0. 14-0. 16	4. 5-6
	22-91	Gravelly clay	CH	A-7	75-85	70-80	60-70	0. 2-0. 63	0. 11-0. 13	4. 5-6
Hillsboro: HlA, HlB, HlC, HlD, HlE, HlF.	0-36	Loam	ML	A-4	--------	100	55-65	0. 63-2. 0	0. 16-0. 18	5. 1-6
	36-62	Sandy loam and sand.	SM	A-1	95-100	95-100	15-25	2. 0-6. 3	0. 10-0. 12	5. 6-7.
HoA, HoB, HoC, HoD, HoE, HoG, HsB.	0-86	Silt loam (boulders on surface of HsB).	ML	A-4	--------	100	80-90	0. 63-2. 0	0. 19-0. 21	5. 0-6.

See footnotes at end of table.

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TABLE 7.—*Estimated physical and chemical properties of the soils*—Continued

Soil series and map symbols	Depth from surface	Classification			Percentage passing sieve—			Permeability	Available water capacity	Reaction
		Dominant USDA texture	Unified	AASHO	No. 4 (4.76 mm.)[1]	No. 10 (2.0 mm.)	No. 200 (0.074 mm.)			
	Inches							*Inches per hour*	*Inches per inch of soil*	*pH*
dson: HtA, HuB, HvA. For properties of the Dollar part of HvA, see Dollar series.	0-23	Loam	ML or CL	A-4	--------	100	55-65	0.63-2.0	0.16-0.18	5.1-6.0
	23-31	Fine sandy loam and loam.	SC or CL	A-4	--------	100	45-55	0.06-0.2	0.14-0.16	5.6-6.5
	31-74	Silt loam	ML	A-4	--------	100	60-70	0.2-0.63	0.19-0.21	5.6-6.5
y: KeC, KeE, KeF, KnF.	0-60	Gravelly silt loam, gravelly silty clay loam, and gravelly clay loam.	ML	A-7	70-100	65-95	55-75	0.63-2.0	0.14-0.16	5.1-6.0
	60	Weathered igneous rock.								
mount: LaE, LaG.	0-62	Cobbly silt loam and clay loam.	ML	A-4	[3] 55-75	50-70	35-50	0.63-2.0	0.12-0.14	4.5-6.5
	62	Fractured bedrock.								
LcG.	0-62	Silt loam and clay loam.	ML	A-4	[4] 30-55	25-50	15-35	0.63-2.0	0.08-0.10	4.5-6.5
	62	Fractured bedrock.								
Lauren: LaB, LgB, LgD, LgF, LlB.	0-33	Very gravelly loam.	GM	A-2	40-50	35-50	20-35	0.63-2.0	0.08-0.10	5.6-7.3
	33-70	Very gravelly coarse sandy loam.	GM	A-1	40-50	35-50	5-15	6.3-20.0	0.06-0.08	6.1-7.3
	70	Very gravelly loamy coarse sand.								
LrC, LrF.	0-14	Gravelly loam and gravelly clay loam.	SM	A-4	55-75	50-70	35-50	0.63-2.0	0.12-0.14	6.1-7.3
	14-35	Very gravelly clay loam (weakly cemented).	GC	A-2 or A-4	35-50	30-55	20-40	0.63-2.0	0.10-0.12	6.1-7.3
	35-60	Very gravelly clay loam.	GC	A-2	25-45	20-40	15-30	<0.06	0.04-0.06	6.1-7.3
McBee: McB, McA.	0-65	Silty clay loam, clay.	CL	A-6	--------	100	80-90	0.63-2.0	0.19-0.21	5.6-6.0
MlA.	0-19	Silt loam and loam.	ML	A-4	90-95	85-95	50-60	0.63-2.0	0.17-0.19	6.1-7.3
	19-44	Gravelly fine sandy loam.	SM	A-4	75-90	70-85	35-50	0.63-2.0	0.10-0.12	6.1-7.3
	44-62	Very gravelly loamy sand.	GM	A-1	35-50	30-50	5-15	>20.0	0.04-0.06	6.1-7.3

See footnotes at end of table.

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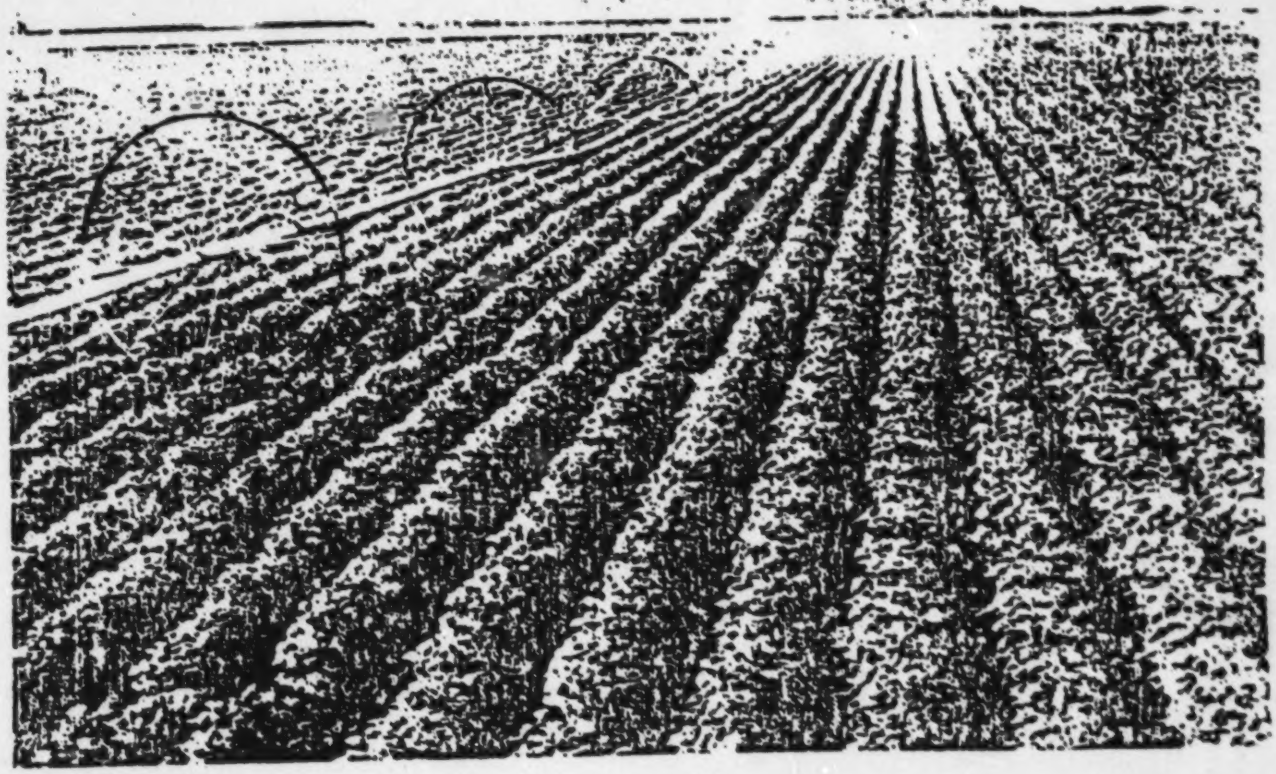
SOIL SURVEY OF

CASSIA COUNTY, IDAHO, WESTERN PART



United States Department of Agriculture,
Soil Conservation Service and
United States Department of the Interior,
Bureau of Land Management
in cooperation with
University of Idaho, Agricultural Experiment Station

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DEPOSITORY
UNIVERSITY OF NEW HAMPSHIRE

SOIL SURVEY OF CASSIA COUNTY, IDAHO, WESTERN PART

By Harold B. Maxwell, Soil Conservation Service

Fieldwork by Glen H. Logan, Darwin Jeppesen, Larry E. Laing, and Gary Muckel, Soil Conservation Service

Others contributing were: David Van Houten, Russell A. Collett, and James R. Stalnaker

United States Department of Agriculture, Soil Conservation Service and
United States Department of the Interior, Bureau of Land Management,
in cooperation with University of Idaho, Agricultural Experiment Station

CASSIA COUNTY, IDAHO, WESTERN PART is in the extreme south-central part of Idaho (see facing page). The western part is north of the boundary line between townships 14 and 15. Cassia County is bounded on the east by the Albion Mountains. It is bounded on the north by the Snake River and on the west by Twin Falls County. It has a total area of 366,720 acres, or 573 square miles. Elevations vary between about 4,100 feet at the shoreline of the Snake River and 7,000 feet along the eastern boundary in the Albion Mountain Range.

The survey area consists of the wide, low gradient, Goose Creek Valley merging with the Snake River Plain. The contact between the two is gradual and not well defined. The soils in Goose Creek Valley formed in water-deposited materials, and the soils on the Snake River Plain formed in wind-laid and water-deposited materials over lava flows. The Valley joins the Albion Mountain Range on the east, Middle Mountain on the south, and the Bostetter Mountain Range on the west. The soils on the hills and mountains are moderately deep, and shallow over limestone, quartzite, and lava.

General nature of the county

This section gives general information concerning the county. It discusses settlement, natural resources, climate, and farming.

Settlement of the county

Before 1800 there were no known permanent residents in this area (*1*). Indians used the area for hunting, trapping, and temporary campgrounds. The early trappers recorded that elk and buffalo were plentiful. The earliest written record of explorers or trappers in this area included Lewis and Clark in 1805 and trappers of the Pacific Fur Company in 1811 and of the Hudson Bay Fur Company in 1825. The historic Oregon Trail crosses the northern part of the survey area. The early pioneers passed through and used the area to harvest game for food.

Early settlers were located along creekbanks within the area after completion of the first transcontinental railroad in 1869. Many former railroad workers moved north into the area. Cattlemen, sheepmen, and fur traders also settled there. Mormon settlements were also responsible for the early development in much of the area, especially in the town of Oakley.

Cattle raising was the main type of agriculture until about 1900 when the sheep industry became most prominent. Irrigated farming was introduced about 1911.

In 1911, an earth dam and canals were constructed at the mouth of Goose Creek Canyon. The reservoir collects water from Trapper, Birch, Cottonwood, and Goose Creeks. It was believed that the earth dam, the largest in the world at that time, would collect enough water for all the land to be farmed. This was disproved, and fewer acres than originally planned were irrigated.

The Minidoka Dam, on the Snake River, was completed in 1908. Sufficient water to properly irrigate the project was not received until 1910 and 1911. The Burley Irrigation District was organized in 1918. The plan of construction provided for 3 lifts in the northern part of the survey area. The first irrigation well was drilled in 1950. Since then, deep wells have become an important source of irrigation water.

Natural resources

Soil and water are the most important natural resources in the survey area. Crops produced on the farms and the livestock that graze the grassland are marketable products derived from the natural resources.

The northern part of the survey area receives water from the Snake River and has adequate water supplies. Most of the other areas receive water from local runoff or irrigation wells. These sources are not always dependable, and sometimes production is reduced. The Bureau of Reclamation is studying the feasibility of supplying water from the Snake River to other parts of the survey area.

Industry in the survey area is mostly connected with agriculture. It employs food processors, seed and fertilizer suppliers, and farm equipment suppliers.

TABLE 15.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS

[The symbol < means less than. Entries under "Erosion factors--T" apply to the entire profile. Entries under "Wind erodibility group" apply only to the surface layer. Absense of an entry indicates that data were not available or were not estimated]

Soil name and map symbol	Depth	Permea-bility	Available water capacity	Soil reaction	Salinity	Shrink-swell potential	Risk of corrosion		Erosion factors		Wind erodi-bility group
							Uncoated steel	Concrete	K	T	
	In	In/hr	In/in	pH	Mmhos/cm						
Abo:											
1----------------	0-6	0.2-0.6	0.16-0.20	7.4-8.4	2-4	Moderate	High-----	Low------	0.32	4	6
	6-14	0.2-0.6	0.16-0.20	7.4-8.4	2-4	Moderate	High-----	Low------	0.28		
	14-51	0.2-0.6	0.16-0.20	7.4-9.0	2-4	Moderate	High-----	Low------	0.28		
	51-60	6.0-20	0.04-0.07	7.4-9.0	<2	Low--------	High-----	Low------	0.10		
Abo Variant:											
2----------------	0-12	0.2-0.6	0.10-0.13	7.4-9.0	8-16	Moderate	High-----	Low------	0.32	4	6
	12-25	0.2-0.6	0.08-0.12	7.9-9.0	8-16	Moderate	High-----	Low------	0.23		
	25-55	0.2-0.6	0.10-0.13	7.9-9.0	4-8	Moderate	High-----	Low------	0.23		
	55-60	6.0-20	0.04-0.07	7.9-9.0	<4	Low--------	High-----	Low------	0.17		
Alpowa:											
3, 4--------------	0-10	2.0-6.0	0.13-0.18	7.4-8.4	<2	Low--------	Moderate	Low------	0.43	2	6
	10-60	2.0-6.0	0.04-0.10	7.9-8.4	<2	Low--------	Moderate	Low------	0.24		
5----------------	0-10	2.0-6.0	0.11-0.18	7.4-8.4	<2	Low--------	Moderate	Low------	0.43	2	6
	10-48	2.0-6.0	0.04-0.08	7.4-8.4	<2	Low--------	High-----	Low------	0.24		
6----------------	0-7	2.0-6.0	0.08-0.12	7.4-8.4	<2	Low--------	Moderate	Low------	0.24	1	3
	7-60	2.0-6.0	0.04-0.10	7.9-8.4	<2	Low--------	Moderate	Low------	0.24		
Aysees:											
7----------------	0-6	2.0-6.0	0.09-0.12	7.9-8.4	<2	Low--------	Moderate	Low------	0.24	5	6
	6-16	2.0-6.0	0.06-0.09	7.9-9.0	<2	Low--------	High-----	Low------	0.10		
	16-60	6.0-20	0.04-0.08	7.9-9.0	<2	Low--------	High-----	Low------	0.10		
Bedcke:											
8, 9--------------	0-8	0.6-2.0	0.15-0.20	6.6-8.4	<2	Low--------	Moderate	Low------	0.37	5	6
	8-21	0.2-0.6	0.16-0.20	7.4-9.0	<2	Moderate	High-----	Low------	0.43		
	21-60	0.6-2.0	0.10-0.18	7.9-9.0	2-4	Low--------	High-----	Low------	0.43		
Beetville:											
10---------------	0-13	0.6-2.0	0.16-0.18	7.4-8.4	<2	Low--------	Moderate	Low------	0.43	5	6
	13-49	0.6-2.0	0.16-0.20	7.4-8.4	<2	Low--------	Moderate	Low------	0.43		
	49-60	6.0-20	0.03-0.08	7.4-8.4	<2	Low--------	Low------	Low------	0.55		
Bram:											
11---------------	0-52	0.2-0.6	0.08-0.11	>9.0	8-16	Low--------	High-----	Low------	0.43	5	4L
	52-60	2.0-6.0	0.07-0.10	>9.0	8-16	Low--------	High-----	Low------	0.24		
Buko:											
[1]12:											
Buko part-------	0-10	0.6-2.0	0.14-0.19	7.4-8.4	<2	Low--------	Moderate	Low------	0.43	2	5
	10-20	0.2-0.6	0.18-0.20	7.9-8.4	<2	Moderate	Moderate	Low------	0.43		
	20-34	0.2-0.6	0.14-0.20	7.9-8.4	<2	Low--------	High-----	Low------	0.32		
	34-60	6.0-20	0.03-0.07	7.9-8.4	<2	Low--------	Low------	Low------	0.10		
Paniogue part---	0-9	0.6-2.0	0.17-0.19	7.4-8.4	<2	Low--------	High-----	Low------	0.43	2	5
	9-32	0.6-2.0	0.14-0.18	7.4-8.4	<2	Low--------	High-----	Low------	0.49		
	32-60	>20	0.04-0.08	7.9-9.0	<2	Low--------	Low------	Low------	0.10		
[1]13:											
Buko part-------	0-15	0.6-2.0	0.14-0.19	7.4-8.4	<2	Low--------	Moderate	Low------	0.43	2	5
	15-30	0.6-2.0	0.14-0.20	7.9-8.4	<2	Low--------	High-----	Low------	[illegible]		
	30-60	6.0-20	0.03-0.07	7.9-8.4	<2	Low--------	High-----	Low------	0.10		
Paniogue part---	0-6	0.6-2.0	0.17-0.19	7.4-8.4	<2	Low--------	Moderate	Low------	0.43	2	5
	6-24	0.6-2.0	0.15-0.17	7.9-8.4	<2	Low--------	High-----	Low------	0.43		
	24-60	6.0-20	0.04-0.07	7.9-8.4	<2	Low--------	High-----	Low------	0.10		
Deelo:											
14---------------	0-10	2.0-6.0	0.16-0.18	7.4-8.4	<2	Low--------	High-----	Low------	0.28	5	3
	10-28	0.6-2.0	0.19-0.21	7.9-8.4	2-4	Low--------	High-----	Low------	0.43		
	28-60	0.6-2.0	0.17-0.21	7.9-8.4	2-4	Low--------	High-----	Low------	0.37		

See footnote at end of table.

TABLE 15.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS--Continued

Soil name and map symbol	Depth	Permeability	Available water capacity	Soil reaction	Salinity	Shrink-swell potential	Risk of corrosion		Erosion factors		Wind erodibility group
							Uncoated steel	Concrete	K	T	
	In	In/hr	In/in	pH	Mmhos/cm						
Declo:											
15, 16, 17--------	0-10	0.6-2.0	0.19-0.21	7.4-8.4	<2	Low--------	High-----	Low------	0.37	5	4L
	10-44	0.6-2.0	0.19-0.21	7.9-9.0	2-4	Low--------	High-----	Low------	0.43		
	44-60	0.6-2.0	0.17-0.21	7.9-9.0	2-4	Low--------	High-----	Low------	0.37		
Dismutel:											
18, 19------------	0-24	0.6-2.0	0.16-0.18	7.9-8.4	<2	Low--------	Moderate	Low------	0.37	5	5
	24-60	0.6-2.0	0.13-0.17	7.9-9.0	<4	Low--------	High-----	Low------	0.32		
Drax:											
20----------------	0-14	0.2-2.0	0.19-0.21	7.4-8.4	<2	Moderate	High-----	Low------	0.37	5	6
	14-60	0.6-2.0	0.19-0.21	7.4-8.4	<2	Moderate	High-----	Low------	0.32		
21----------------	0-14	0.2-2.0	0.19-0.21	7.4-8.4	<2	Moderate	High-----	Low------	0.37	5	6
	14-60	0.6-2.0	0.19-0.21	7.4-8.4	<2	Moderate	High-----	Low------	0.37		
Escalante:											
22, 23, 24--------	0-5	2.0-6.0	0.10-0.14	7.4-9.0	2-4	Low--------	High-----	Low------	0.28	3	3
	5-47	2.0-6.0	0.10-0.12	7.4-8.4	2-4	Low--------	High-----	Low------	0.28		
	47-60	2.0-6.0	0.02-0.04	7.4-8.4	2-4	Low--------	High-----	Low------	0.15		
Garbutt:											
25, 26------------	0-45	0.6-2.0	0.18-0.20	7.9-9.0	<2	Low--------	High-----	Low------	0.49	5	4L
	45-60	0.6-2.0	0.11-0.13	7.9-9.0	2-8	Low--------	High-----	Low------	0.32		
Goose Creek:											
27----------------	0-22	0.2-2.0	0.19-0.21	7.4-8.4	<2	Moderate	High-----	Low------	0.37	5	6
	22-60	0.2-0.6	0.13-0.18	7.4-8.4	<2	Moderate	High-----	Low------	0.43		
28, 29------------	0-24	0.2-0.6	0.19-0.21	7.4-8.4	<2	Moderate	High-----	Low------	0.32	5	7
	24-60	0.2-0.6	0.13-0.18	7.4-8.4	<2	Moderate	High-----	Low------	0.43		
Hymas:											
[1]30:											
Hymas part------	0-8	0.6-2.0	0.09-0.15	7.4-8.4	<2	Low--------	Moderate	Low------	0.43	1	8
	8-17	0.6-2.0	0.06-0.09	7.9-8.4	<2	Low--------	Moderate	Low------	0.20		
	17	---	---	---	---	----------	---------	---------	---		
Rock outcrop part.											
Itca:											
[1]31:											
Itca part--------	0-4	0.6-6.0	0.05-0.10	7.4-8.4	<2	Low--------	Moderate	Low------	0.24	1	8
	4-17	0.06-0.2	0.08-0.12	7.4-8.4	<2	Moderate	High-----	Low------	0.10		
	17	---	---	---	---	----------	---------	---------	---		
Kanlee part-----	0-10	0.6-2.0	0.13-0.17	6.6-7.8	<2	Low--------	Moderate	Low------	0.15	2	8
	10-38	0.2-0.6	0.13-0.19	6.6-7.8	<2	Moderate	Moderate	Low------	0.24		
	38	---	---	---	---	----------	---------	---------	---		
Kissama:											
32----------------	0-60	0.6-2.0	0.19-0.21	7.4-9.0	<2	Low--------	High-----	Low------	0.43	5	6
Kucera:											
33, 34------------	0-60	0.6-2.0	0.19-0.21	7.4-9.0	<2	Low--------	High-----	Low------	0.49	5	5
Mackey:											
[1]35:											
Mackey part-----	0-4	2.0-6.0	0.08-0.11	7.4-8.4	<2	Low--------	Moderate	Low------	0.24	2	8
	4-12	2.0-6.0	0.08-0.11	7.4-8.4	<2	Low--------	Moderate	Low------	0.20		
	12-32	2.0-6.0	0.03-0.07	7.9-9.0	<2	Low--------	High-----	Low------	0.10		
	32	---	---	---	---	----------	---------	---------	---		
Rock outcrop part.											

See footnote at end of table.

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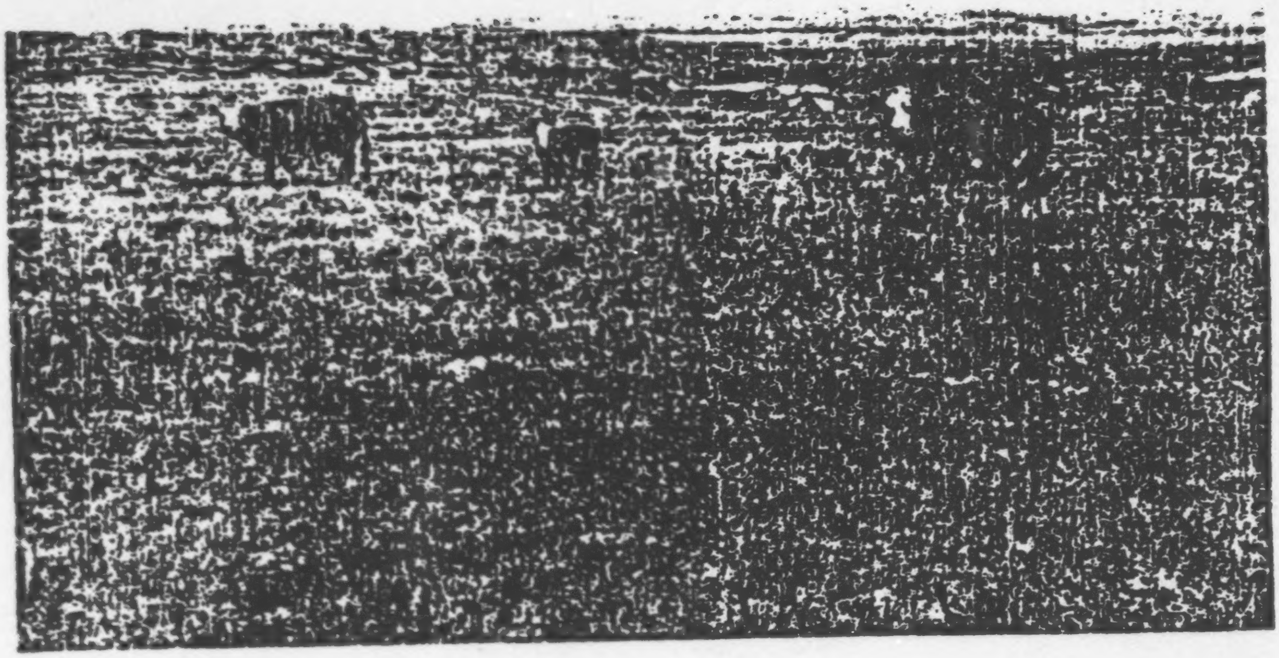
SOIL SURVEY OF

Barber County, Kansas



United States Department of Agriculture
Soil Conservation Service
In cooperation with
Kansas Agricultural Experiment Station

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SOIL SURVEY OF BARBER COUNTY, KANSAS

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UNITED STATES DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE, IN COOPERATION WITH THE KANSAS AGRICULTURE EXPERIMENT STATION

BARBER COUNTY, in the south-central part of Kansas, has a total area of 1,146 square miles, or 733,218 acres (fig. 1). Medicine Lodge, which is in the east-central part of the county at the confluence of Medicine River and Elm Creek, is the county seat.

Ranching and farming are important enterprises in the county. Beef cattle are the major livestock, but some dairy cows are kept. Winter wheat, grain and forage sorghums, and alfalfa are the major crops.

Irrigation is practiced on a few farms in the Sharon Valley, the Medicine River Valley, and in an area near Isabel.

How This Survey Was Made

Soil scientists made this survey to learn what kinds of soil are in Barber County, where they are located, and how they can be used. The soil scientists went into the county knowing they were likely to find many soils they had already seen and perhaps some they had not. They observed the steepness, length, and shape of slopes, the size and speed of streams, the kinds of native plants or crops, the kinds of rock, and many facts about the soils. They dug many holes to expose soil profiles. A profile is the sequence of natural layers, or horizons, in a soil; it extends from the surface down into the parent material that has not been changed much by leaching or by the action of plant roots.

The soil scientists made comparisons among the profiles they studied, and they compared these profiles with those in counties nearby and in places more distant. They classified and named the soils according to nationwide, uniform procedures. The *soil series* and the *soil phase* are the categories of soil classification most used in a local survey.

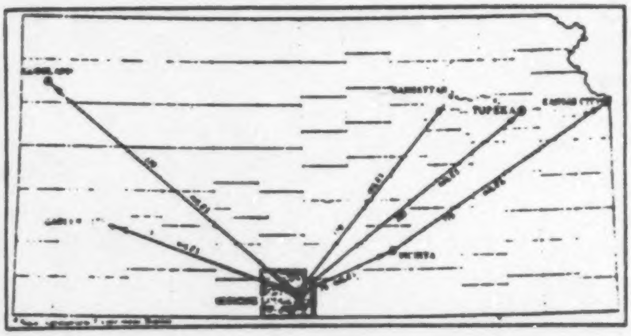

Figure 1.—Location of Barber County in Kansas.

Soils that have profiles almost alike make up a soil series. Except for different texture in the surface layer, all the soils of one series have major horizons that are similar in thickness, arrangement, and other important characteristics. Each soil series is named for a town or other geographic feature near the place where a soil of that series was first observed and mapped. Grant and Pond Creek, for example, are the names of two soil series. All the soils in the United States having the same series name are essentially alike in those characteristics that affect their behavior in the undisturbed landscape.

Soils of one series can differ in texture of the surface layer and in slope, stoniness, or some other characteristic that affects use of the soils by man. On the basis of such differences, a soil series is divided into phases. The name of a soil phase indicates a feature that affects management. For example, Grant silt loam, 0 to 1 percent slopes, is one of several phases within the Grant series.

After a guide for classifying and naming the soils had been worked out, the soil scientist drew the boundaries of the individual soils on aerial photographs. These photographs show woodlands, buildings, field borders, trees, and other details that help in drawing boundaries accurately. The soil map at the back of this publication was prepared from aerial photographs.

The areas shown on a soil map are called mapping units. On most maps detailed enough to be useful in planning the management of farms and fields, a mapping unit is nearly equivalent to a soil phase. It is not exactly equivalent, because it is not practical to show on such a map all the small, scattered bits of soil of some other kind that have been seen within an area that is dominantly a recognized soil phase.

Some mapping units are made up of soils of different series, or no series name is assigned. Two such kinds of mapping units are shown on the soil map of Barber County: soil complexes and miscellaneous land types.

A soil complex consists of areas of two or more soils,

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[1] WILLIAM E. ROTH, soil scientist, Soil Conservation Service, helped survey the Davis Ranch along the Salt Fork of the Arkansas River.

TABLE 3.—*Estimated soil properties*

Soil series and map symbols	Depth to—		Depth from surface	USDA texture	Classification	
	Bedrock	Seasonal high water table			Unified	AASHTO
	Feet	*Feet*	*Inches*			
Ost: Os, Ot	>5	>6	0–8	Clay loam	CL	A–6
			8–28	Clay loam	CL	A–7
			28–60	Clay loam	CL	A–6
Pond Creek: Pa, Pd	>5	>6	0–11	Silt loam	ML or CL	A–4
			11–45	Silty clay loam	CL	A–6 or A–7
			45–60	Heavy silt loam	CL	A–6
Port: Ph, Pk For Slickspots part of Pk, properties too variable to be estimated.	>5	>6	0–20	Silt loam	ML or CL	A–4
			20–32	Heavy silt loam	CL	A–4 or A–6
			32–60	Silt loam	CL	A–6
*Pratt: Ps, Pt For Tivoli part of Pt, see Tivoli series.	>5	>5	0–60	Loamy fine sand	SM	A–2
*Quinlan: Qn, Qw For Woodward part of Qw, see Woodward series.	1–1½	>6	0–14	Loam	ML or CL	A–4
				Weakly cemented sandstone.		
Rough broken land, shaly: Rb. Too variable to be estimated.						
Shale outcrop. Mapped only in a complex with Vernon series. Properties too variable to be estimated.						
Shellabarger: Sb, Sc	>5	>6	0–14	Sandy loam	SM	A–4 or A–2
			14–48	Sandy clay loam	SC	A–6
			48–60	Sandy loam	SM or SC	A–2
Slickspots. Mapped only in complexes with Mangum and Port series. Too variable to be estimated.						
Tivoli: Tv	>5	>5	0–60	Fine sand	SP or SM	A–2 or A–3
Vernon: Ve, Vr, Vs For Shale outcrop part of Vs, properties too variable to be estimated.	2–4	>10	0–5	Clay loam	CL	A–6 or A–7
			5–22	Clay	CL or CH	A–7
			22–60	Clay shale	CL or CH	A–6 or A–7
Waldeck: Wa	>5	2–5	0–36	Sandy loam	SM or ML	A–4
			36–60	Fine and medium sand	SP or SM	A–3 or A–2
*Woodward: Wo, Ws Mapped only in complexes with Quinlan soils. For Quinlan parts, see Quinlan series.	1½–4	>6	0–40	Loam	ML or CL	A–4
			40–60	Fine-grained sandstone.		
Yahola: Ya	>5	4–6	0–60	Sandy loam	SM or ML	A–4 or A–2
			60–66	Medium sand	SM	A–2
Zenda: Za	>5	3–6	0–60	Clay loam	CL	A–6

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[1] NP means nonplastic.

significant to engineering—Continued

Percentage less than 3 inches passing sieve—				Liquid limit	Plasticity index	Permeability	Available water capacity	Reaction	Shrink-swell potential
No. 4 (4.7 mm)	No. 10 (2.0 mm)	No. 40 (0.42 mm)	No. 200 (0.074 mm)						
						Inches per hour	*Inches per inch of soil*	*pH*	
100	100	90–100	80–95	25–40	8–18	0.6–2.0	0.17–0.19	6.1–6.5	Moderate.
100	100	90–100	80–95	40–50	20–30	0.2–0.6	0.15–0.19	6.6–8.4	Moderate.
100	100	90–100	80–95	25–40	8–18	0.2–0.6	0.14–0.16	7.9–8.4	Moderate.
100	100	95–100	90–100	20–35	4–10	0.6–2.0	0.22–0.24	6.1–6.5	Low.
100	100	95–100	90–100	30–45	10–25	0.2–0.6	0.18–0.20	6.6–7.3	Moderate.
100	100	95–100	80–95	25–40	8–20	0.2–0.6	0.18–0.20	7.4–7.8	Moderate.
100	100	90–100	70–90	20–35	4–10	0.6–2.0	0.22–0.24	6.1–6.5	Low.
100	100	95–100	75–95	25–40	8–20	0.6–2.0	0.20–0.22	7.4–7.8	Moderate.
100	100	95–100	85–95	25–40	10–20	0.6–2.0	0.20–0.22	7.9–8.4	Low.
100	100	85–100	15–25	NP	NP	6.0–20.0	0.09–0.11	6.1–7.3	Low.
100	100	90–100	55–85	20–35	3–8	2.0–6.0	0.20–0.22	7.9–8.4	Low.
100	100	70–85	30–50	15–25	2–7	0.6–2.0	0.13–0.15	6.1–6.5	Low.
100	100	70–85	36–50	25–40	11–25	0.6–2.0	0.16–0.18	6.1–6.5	Low.
100	100	50–75	20–35	25–40	11–25	0.6–2.0	0.09–0.13	6.1–7.3	Low.
100	100	85–95	5–15	NP	NP	6.0–20.0	0.05–0.07	6.1–6.5	Very low.
100	100	90–100	80–95	30–50	10–30	0.06–0.2	0.17–0.19	7.9–8.4	Moderate.
100	100	95–100	85–100	35–60	20–40	<0.06	0.09–0.11	7.9–8.4	High.
90–100	85–100	65–100	60–100	30–60	15–35	<0.06	0.08–0.14	7.9–8.4	High.
100	100	80–95	40–70	NP–26	NP–6	2.0–6.0	0.13–0.15	7.4–8.4	Low.
100	90–100	80–95	5–20	NP	NP	6.0–20.0	0.05–0.07	7.4–8.4	Low.
100	100	90–100	65–100	20–30	4–10	0.6–2.0	0.17–0.19	7.4–8.4	Low.
100	100	85–95	30–60	NP–26	NP–6	2.0–6.0	0.15–0.17	7.9–8.4	Low.
100	90–100	50–90	15–35	NP	NP	6.0–20.0	0.05–0.07	7.9–8.4	Low.
100	95–100	85–95	60–75	30–40	15–25	0.6–2.0	0.15–0.19	6.6–8.4	Moderate.

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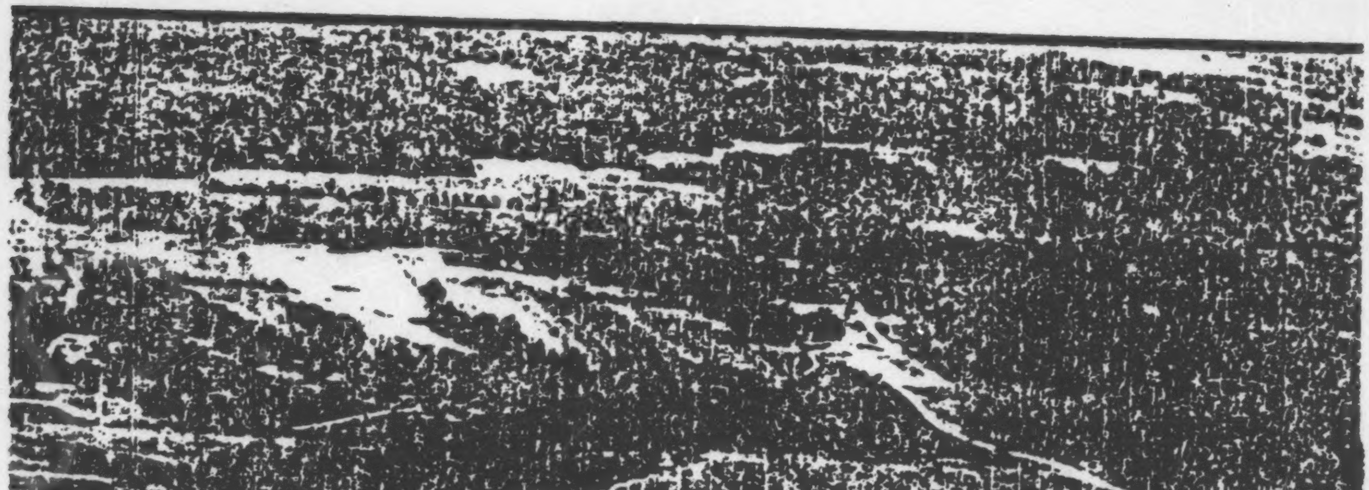
Soil Survey of

Morgan County Indiana

United States Department of Agriculture, Soil Conservation Service
in cooperation with Purdue University, Agricultural Experiment Station,
and Indiana Department of Natural Resources, Soil and Water Conservation Committee



soil survey of Morgan County, Indiana

By Ralph H. Sturm, Soil Conservation Service

Fieldwork by Ralph H. Sturm, James R. Blank, and Charles E. Froehle,
Soil Conservation Service,
and Stephen K. Kluess and Terry L. Stephenson,
Indiana Department of Natural Resources, Soil and Water Conservation Committee

United States Department of Agriculture, Soil Conservation Service
in cooperation with Purdue University, Agricultural Experiment Station
and Indiana Department of Natural Resources,
Soil and Water Conservation Committee

MORGAN COUNTY is in the central part of Indiana. It covers an area of about 406 square miles, or 259,840 acres, and is about 20 miles long and 20 miles wide. Martinsville, the county seat and largest city, is located near the center of the southern half of the county.

Farming is the main enterprise in the county. Cash grain and livestock are the major types of farming, but there are also several orchards. Beef cattle and hogs are the livestock most commonly raised.

general nature of the survey area

relief

The highest point in Morgan County is on Long Ridge in Clay Township, about 970 feet above sea level. The lowest point is at the White River in the southwestern corner of the county, at about 550 feet above sea level.

The relief of Morgan County is complex. The northern part is nearly level and rolling and has few abrupt changes in the elevation. The central and southern parts vary more in elevation and have sharp drops of as much as 250 feet from the ridgetops to the bottom lands. Broad flat flood plains are along the White River, which flows from northeast to southwest. The glacial lakebed in the northwestern corner of the county is also broad and flat.

water supply

Ground water is the main source of water in Morgan County. In many areas ground water is scarce because of bedrock. In areas where the overlying unconsolidated material is very thin, most wells terminate in bedrock. These wells supply little or no water, and small manmade ponds or rural water systems are necessary. In areas where wells terminate in glacial till, water yields are usually low to moderate.

The largest and most reliable source of ground water is the valley of the White River and its major tributaries. Large amounts of water can usually be pumped from wells that extend into the thick, coarse textured alluvial deposits in this valley.

climate

Prepared by the National Climatic Center, Asheville, North Carolina.

Morgan County is cold in winter but quite hot in summer. Winter precipitation, frequently snow, results in a good accumulation of soil moisture by spring and minimizes drought during summer on most soils. Normal

TABLE 17.--PHYSICAL AND CHEMICAL PROPERTIES OF THE SOILS

[The symbol < means less than; > means more than. Entries under "Erosion factors--T" apply to the entire profile. Entries under "Wind erodibility group" and "Organic matter" apply only to the surface layer. Absence of an entry indicates that data were not available or were not estimated]

Soil name and map symbol	Depth	Clay	Moist bulk density	Permeability	Available water capacity	Reaction	Salinity	Shrink-swell potential	Erosion factors		Wind erodibility group	Organic matter
									K	T		
	In	Pct	G/cm3	In/hr	In/in	pH	Mmhos/cm					Pct
AfA, AfB, AfC2--- Alford	0-8	18-27	1.25-1.40	0.6-2.0	0.22-0.24	4.5-7.3	<2	Low--------	0.37	5	5	.5-2
	8-40	22-30	1.35-1.50	0.6-2.0	0.18-0.20	4.5-6.5	<2	Moderate	0.37			
	40-70	8-20	1.30-1.45	0.6-2.0	0.20-0.22	4.5-7.3	<2	Low--------	0.37			
Ar--------------- Armiesburg	0-15	24-33	1.30-1.45	0.6-2.0	0.21-0.23	6.1-7.3	<2	Moderate	0.28	5	6	2-4
	15-60	24-33	1.30-1.45	0.6-2.0	0.18-0.20	6.1-7.3	<2	Moderate	0.28			
AvB-------------- Ava	0-14	20-27	1.40-1.60	0.6-2.0	0.22-0.24	4.5-6.5	<2	Moderate	0.43	4	6	1-2
	14-29	22-35	1.40-1.60	0.2-0.6	0.18-0.20	4.5-5.5	<2	Moderate	0.43			
	29-62	25-35	1.60-1.75	0.06-0.2	0.09-0.10	4.5-5.5	<2	Moderate	0.43			
	62-80	20-30	1.65-1.80	<0.06	0.05-0.08	4.5-5.5	<2	Moderate	0.43			
Ba--------------- Banlic	0-7	10-18	1.30-1.50	0.2-0.6	0.22-0.24	4.5-6.5	<2	Low--------	0.43	3	5	.5-2
	7-22	12-18	1.40-1.60	0.06-0.2	0.20-0.22	4.5-6.0	<2	Low--------	0.43			
	22-70	10-20	1.65-1.80	0.06-0.2	0.11-0.12	4.5-6.0	<2	Low--------	0.43			
Bd--------------- Bartle	0-7	15-26	1.30-1.45	0.6-2.0	0.20-0.24	5.1-7.3	<2	Low--------	0.43	4	5	1-3
	7-26	22-35	1.40-1.60	0.6-2.0	0.20-0.22	4.5-5.5	<2	Low--------	0.43			
	26-57	22-35	1.60-1.80	<0.06	0.06-0.08	4.5-5.5	<2	Low--------	0.43			
	57-60	22-35	1.40-1.60	0.2-0.6	0.06-0.08	5.1-7.3	<2	Low--------	0.43			
BeB, BeC2--------- Bedford	0-7	10-16	1.30-1.45	0.6-2.0	0.22-0.24	4.5-5.0	<2	Low--------	0.43	4	5	1-2
	7-27	27-32	1.30-1.45	0.6-2.0	0.18-0.20	4.5-5.5	<2	Moderate	0.43			
	27-49	28-35	1.50-1.70	<0.06	0.06-0.08	4.5-5.5	<2	Moderate	0.43			
	49-80	35-55	1.30-1.50	0.2-0.6	0.06-0.08	4.5-5.5	<2	Moderate	0.32			
BfG-------------- Berks	0-6	5-23	1.20-1.50	0.6-6.0	0.08-0.12	4.5-6.5	<2	Low--------	0.24	3	---	.5-3
	6-24	5-20	1.20-1.60	0.6-2.0	0.04-0.10	4.5-6.5	<2	Low--------	0.17			
	24-30	5-20	1.20-1.60	2.0-6.0	0.04-0.10	4.5-6.5	<2	Low--------	0.17			
	30	---	---	---	---	---	---	----------	----			
BmC-------------- Bloomfield	0-32	3-10	1.60-1.80	6.0-20	0.07-0.12	5.1-7.3	<2	Low--------	0.15	5	1	.5-2
	32-61	6-18	1.60-1.80	6.0-20	0.06-0.17	5.1-6.5	<2	Low--------	0.15			
	61-70	3-18	1.70-1.90	6.0-20	0.06-0.08	5.1-7.3	<2	Low--------	0.15			
Bo--------------- Bonnie	0-8	18-25	1.20-1.40	0.6-2.0	0.22-0.24	6.6-7.3	<2	Low--------	0.43	5	6	1-3
	8-60	18-25	1.40-1.60	0.2-0.6	0.20-0.22	4.5-5.5	<2	Low--------	0.43			
Br--------------- Brookston	0-17	27-32	1.40-1.55	0.6-2.0	0.21-0.24	6.1-7.3	<2	Moderate	0.28	5	7	3-5
	17-49	27-35	1.40-1.60	0.6-2.0	0.15-0.19	6.6-7.3	<2	Moderate	0.28			
	49-60	15-32	1.45-1.70	0.6-2.0	0.05-0.19	7.4-8.4	<2	Moderate	0.28			
ChF-------------- Chetwynd	0-9	12-24	1.30-1.50	0.6-2.0	0.20-0.24	5.6-7.3	<2	Low--------	0.32	5	5	1-3
	9-44	22-35	1.40-1.60	0.6-2.0	0.13-0.17	4.5-5.5	<2	Moderate	0.32			
	44-57	20-30	1.35-1.60	0.6-2.0	0.11-0.17	5.1-6.0	<2	Low--------	0.32			
	57-72	3-10	1.40-1.60	2.0-6.0	0.12-0.19	5.1-6.0	<2	Low--------	0.15			
CnC2, CnC3, CnD2, CnD3------------- Cincinnati	0-16	15-25	1.30-1.50	0.6-2.0	0.22-0.24	4.5-7.3	<2	Low--------	0.37	4-3	6	1-3
	16-23	22-35	1.45-1.65	0.6-2.0	0.15-0.19	4.5-5.5	<2	Low--------	0.37			
	23-47	24-35	1.60-1.85	0.06-0.2	0.08-0.12	4.5-6.5	<2	Moderate	0.37			
	47-80	18-40	1.55-1.75	0.06-0.2	0.14-0.18	4.5-7.8	<2	Low--------	0.37			
CrA-------------- Crosby	0-8	11-22	1.40-1.55	0.6-2.0	0.20-0.24	5.1-7.3	<2	Low--------	0.43	3	5	1-3
	8-36	35-42	1.50-1.70	0.06-0.2	0.15-0.20	5.1-7.3	<2	Moderate	0.43			
	36-60	15-32	1.70-2.00	0.06-0.2	0.05-0.19	7.9-8.4	<2	Low--------	0.43			

TABLE 17.--PHYSICAL AND CHEMICAL PROPERTIES OF THE SOILS--Continued

Soil name and map symbol	Depth	Clay	Moist bulk density	Permea- bility	Available water capacity	Reaction	Salinity	Shrink- swell potential	Erosion factors K	Erosion factors T	Wind erodi- bility group	Organic matter
	In	Pct	G/cm3	In/hr	In/in	pH	Mmhos/cm					Pct
MeA, MeB	0-9	8-17	1.30-1.45	0.6-2.0	0.20-0.24	5.6-7.3	<2	Low	0.37	5	5	1-3
Martinsville	9-46	18-30	1.40-1.60	0.6-2.0	0.17-0.20	5.1-6.0	<2	Moderate	0.37			
	46-50	10-25	1.40-1.60	0.6-2.0	0.12-0.14	5.6-6.5	<2	Low	0.24			
	50-50	3-23	1.50-1.70	0.6-2.0	0.19-0.21	6.5-8.4	<2	Low	0.24			
MnB2, Mn^ . MnD2, MnE	0-7	11-22	1.40-1.55	0.6-2.0	0.20-0.24	5.6-7.3	<2	Low	0.37	5	5	.5-3
Miami	7-32	25-35	1.45-1.65	0.6-2.0	0.15-0.20	5.6-7.3	<2	Moderate	0.37			
	32-60	15-32	1.55-1.90	0.2-0.6	0.05-0.19	6.6-8.4	<2	Low	0.37			
MnF	0-6	11-22	1.40-1.55	0.6-2.0	0.20-0.24	5.6-7.3	<2	Low	0.37	5	5	.5-3
Miami	6-24	25-35	1.45-1.65	0.6-2.0	0.15-0.20	5.6-7.3	<2	Moderate	0.37			
	24-60	15-32	1.55-1.90	0.2-0.6	0.05-0.19	6.6-8.4	<2	Low	0.37			
MoC3, MoD3	0-7	27-35	1.45-1.60	0.6-2.0	0.18-0.20	5.6-7.3	<2	Moderate	0.37	4	6	.5-3
Miami	7-30	25-35	1.45-1.65	0.6-2.0	0.15-0.20	5.6-7.3	<2	Moderate	0.37			
	30-60	15-32	1.55-1.90	0.2-0.6	0.05-0.19	6.6-8.4	<2	Low	0.37			
Mp	0-11	35-42	1.35-1.55	0.6-2.0	0.12-0.23	5.6-7.3	<2	High	0.28	5	4	5-6
Milford	11-48	35-42	1.45-1.65	0.2-0.6	0.18-0.20	5.1-7.3	<2	Moderate	0.43			
	48-60	20-30	1.50-1.70	0.2-0.6	0.20-0.22	6.5-8.4	<2	Moderate	0.43			
Mu	0-12	35-40	1.35-1.55	0.2-0.6	0.20-0.23	6.6-7.8	<2	High	0.37	5	7	3-6
Montgomery	12-45	35-55	1.45-1.65	<0.06	0.11-0.18	6.6-7.8	<2	High	0.37			
	45-60	35-48	1.50-1.70	<0.06	0.18-0.20	7.4-8.4	<2	Moderate	0.37			
OcA, OcB2	0-13	11-22	1.30-1.45	0.6-2.0	0.20-0.24	5.6-6.5	<2	Low	0.37	5	5	.5-3
Ockley	13-33	27-35	1.45-1.60	0.6-2.0	0.15-0.20	4.5-6.0	<2	Moderate	0.37			
	33-54	20-35	1.40-1.55	0.6-2.0	0.12-0.14	5.6-6.5	<2	Moderate	0.24			
	54-60	2-5	1.60-1.80	>20	0.02-0.04	7.4-8.4	<2	Low	0.10			
PkC2, PkD	0-7	18-27	1.25-1.40	0.6-2.0	0.22-0.24	5.1-6.5	<2	Low	0.37	5	5	.5-2
Parke	7-30	27-35	1.30-1.45	0.6-2.0	0.18-0.20	4.5-5.0	<2	Moderate	0.37			
	30-80	20-30	1.55-1.65	0.6-2.0	0.16-0.18	4.5-5.5	<2	Low	0.28			
Pm	0-11	22-30	1.15-1.35	0.6-2.0	0.21-0.23	6.6-7.3	<2	Moderate	0.28	5	7	3-5
Patton	11-50	27-35	1.25-1.45	0.6-2.0	0.18-0.20	6.1-7.8	<2	Moderate	0.28			
	50-60	22-35	1.30-1.50	0.2-2.0	0.18-0.22	6.5-8.4	<2	Moderate	0.28			
PnB	0-8	15-26	1.30-1.45	0.6-2.0	0.22-0.24	5.6-7.3	<2	Low	0.43	4	5	1-3
Pekin	8-21	27-35	1.40-1.60	0.6-2.0	0.20-0.22	4.5-5.5	<2	Low	0.43			
	21-56	22-30	1.60-1.80	<0.06	0.06-0.08	4.5-6.0	<2	Low	0.43			
	56-60	20-34	1.40-1.60	0.6-2.0	0.06-0.08	5.6-7.3	<2	Low	0.43			
PpA, PpE2	0-13	18-27	1.25-1.40	0.6-2.0	0.22-0.24	5.1-7.3	<2	Low	0.37	5	5	.5-2
Pike	13-50	27-35	1.30-1.45	0.6-2.0	0.18-0.22	4.5-5.5	<2	Low	0.37			
	50-74	18-35	1.30-1.45	0.6-2.0	0.12-0.18	4.5-5.5	<2	Low	0.37			
	74-80	14-20	1.45-1.65	2.0-6.0	0.05-0.12	4.5-8.4	<2	Low	0.37			
PrA, PrB, PrC, PrD, PrE	0-11	12-20	1.35-1.50	0.6-2.0	0.13-0.18	5.6-7.3	<2	Low	0.24	5	3	.5-2
Princeton	11-40	18-25	1.40-1.55	0.6-2.0	0.16-0.18	5.1-6.5	<2	Low	0.32			
	40-53	8-18	1.40-1.55	0.6-2.0	0.12-0.14	5.1-7.3	<2	Low	0.32			
	53-60	4-10	1.45-1.60	2.0-6.0	0.06-0.08	6.1-8.4	<2	Low	0.17			
Ps. Pits												
Rd	0-11	12-20	1.20-1.45	0.6-2.0	0.17-0.24	5.6-7.3	<2	Low	0.37	5	5	2-4
Reesville	11-46	22-35	1.30-1.55	0.2-0.6	0.17-0.22	5.1-8.4	<2	Moderate	0.37			
	46-60	12-25	1.20-1.40	0.2-0.6	0.15-0.18	7.4-8.4	<2	Low	0.37			
Re	0-18	27-35	1.40-1.55	0.06-0.2	0.21-0.23	6.1-7.3	<2	Moderate	0.28	5	5	2-6
Rensselaer	18-47	27-35	1.40-1.60	0.06-0.2	0.15-0.19	6.1-7.3	<2	Moderate	0.28			
	47-60	2-30	1.50-1.70	0.6-2.0	0.19-0.21	6.6-8.4	<2	Low	0.28			

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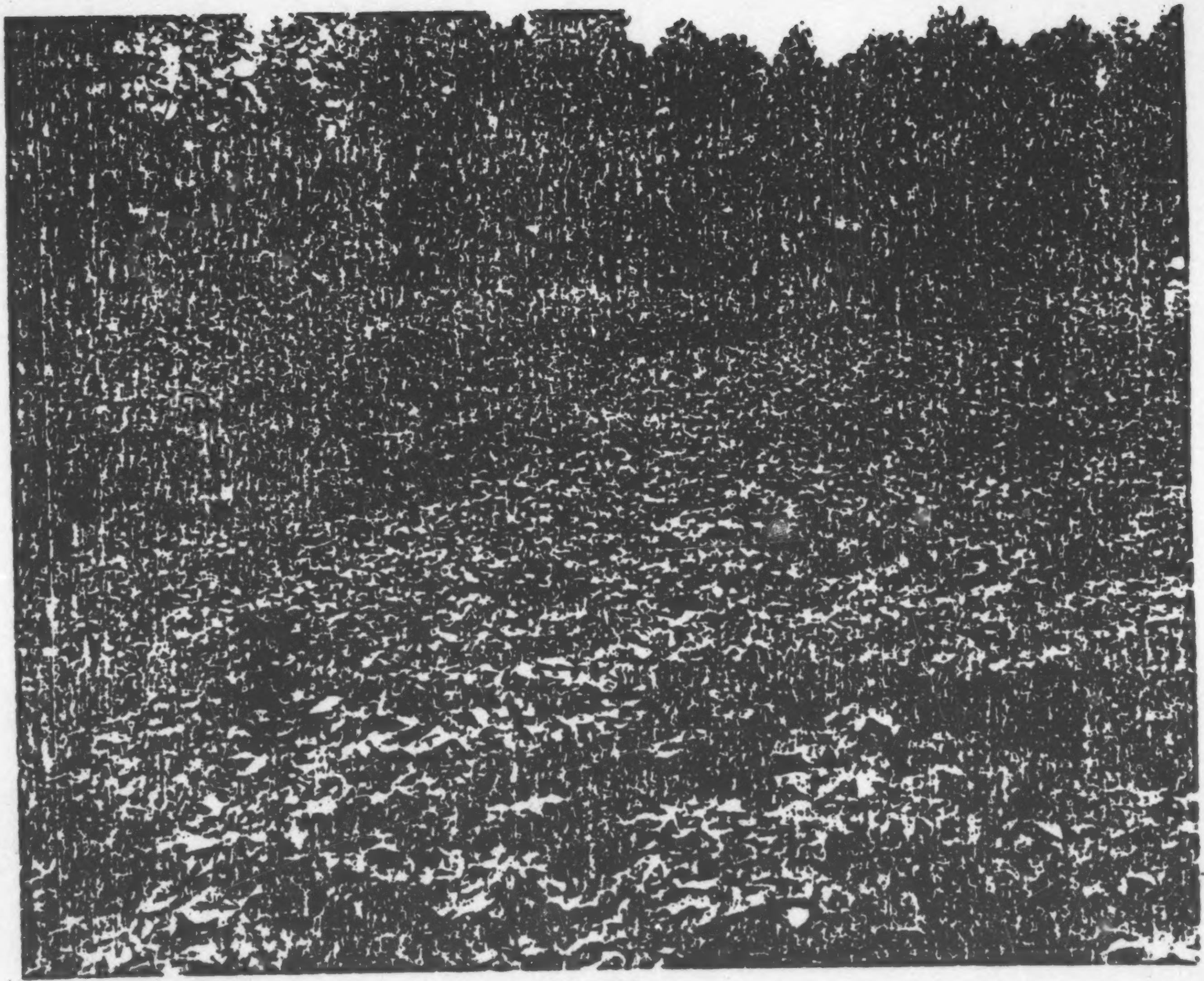
In cooperation with the
Louisiana Agricultural
Experiment Station
and the
Louisiana Soil
and Water
Conservation Committee

Soil Survey of Morehouse Parish Louisiana



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Soil Survey of
Morehouse Parish, Louisiana

By Emmett F. Reynolds, E. Thurman Allen, Teresa L. May, and
Tracey A. Weems, Soil Conservation Service

United States Department of Agriculture,
Soil Conservation Service
in cooperation with the
Louisiana Agricultural Experiment Station and the
Louisiana Soil and Water Conservation Committee

Morehouse Parish is in northeastern Louisiana, about 20 miles northeast of Monroe. The total area is 517,379 acres, of which 505,323 acres is land and 12,056 acres is water in the form of lakes, reservoirs, streams, and other waterways. Morehouse Parish is bordered on the north by Arkansas. The Ouachita River forms the western boundary of the parish, the Boeuf River forms the eastern boundary, and Bayou LaFourche forms the southern boundary. In 1980, the population of the parish was 33,760, according to the Bureau of the Census. Bastrop, with a population of 15,401, is the largest city and the parish seat. The parish is mostly rural, except for the urban and industrial area around Bastrop.

The parish consists of three major physiographic areas. They are the level to gently undulating flood plains, the level to moderately sloping terrace uplands, and the level, low stream terraces. The elevation ranges from about 170 feet above sea level on the terrace uplands southeast of Bastrop to about 50 feet in the backswamps of the Ouachita River in the northwestern part of the parish.

The flood plains make up most of the eastern half of the parish and also extend from north to south along the western edge. They make up nearly three-fourths of the parish. The soils on these flood plains range from loamy to clayey and from well drained to very poorly drained. Most of the acreage is in cultivated crops such as rice. A small acreage is used for homesites, pasture, orchards, and woodland. The loamy soils are on the higher, natural levees of rivers and bayous. These soils are fertile and have few limitations for crops. The clayey soils, which are in the lower areas, are limited by wetness. Some of these clayey soils are flooded by runoff and stream overflow, and drainage is needed for most crops.

The terrace uplands extend from north to south through the central part of the parish and make up about one-fifth of the parish. The soils on these uplands are mainly loamy. They are generally low in natural fertility. Most of the acreage is woodland. A small acreage is used for homesites, pasture, and cultivated crops. Wetness is the main limitation for woodland. Slope and low fertility are additional limitations for crops and pasture. The hazard of erosion is slight to severe.

The low stream terraces make up the remainder of the parish and extend from north to south along the edge of the alluvial plains of the Ouachita River in the western part of the parish. The soils on these terraces are mainly loamy, but some have a clayey subsoil. They are low in natural fertility. Most of the acreage is woodland. A small acreage is in cultivated crops and pasture. Wetness is the main limitation for most uses.

General Nature of the Parish

This section gives general information about the parish. It describes the history and development, agriculture, water resources, climate, transportation, and industry.

History and Development

Morehouse Parish was created from Ouachita Parish by the Legislature of Louisiana in 1844. It was named after Abram Morehouse, who came from Kentucky in 1806 to assist Baron de Bastrop in colonizing the area.

TABLE 16.--ENGINEERING INDEX PROPERTIES--Continued

Map symbol and soil name	Depth	USDA texture	Classification		Fragments > 3 inches	Percentage passing sieve number--				Liquid limit	Plasticity index
			Unified	AASHTO		4	10	40	200		
	In				Pct					Pct	
Rh:*											
Hebert	0-10	Silt loam	ML, CL-ML	A-4	0	100	100	100	65-100	<27	NP-7
	10-37	Loam, silt loam, silty clay loam.	CL	A-6, A-7-6	0	100	100	100	85-100	31-45	11-22
	37-60	Stratified very fine sandy loam to silty clay loam.	ML, CL-ML, CL	A-4, A-6	0	100	100	90-100	60-100	22-40	3-18
Se Sterlington	0-8	Silt loam	ML	A-4	0	100	100	90-100	60-95	<23	NP-3
	8-57	Silt loam, very fine sandy loam, loam.	CL-ML, ML	A-4	0	100	100	90-100	80-95	<28	NP-7
	57-75	Very fine sandy loam, silt loam, loam.	ML, CL-ML	A-4	0	100	100	90-100	80-95	<28	NP-7
Sr Sterlington	0-8	Silt loam	ML	A-4	0	100	100	90-100	60-95	<23	NP-3
	8-60	Silt loam, very fine sandy loam, loam.	CL-ML, ML	A-4	0	100	100	90-100	80-95	<28	NP-7
St:*											
Sterlington	0-15	Silt loam	ML	A-4	0	100	100	90-100	60-95	<23	NP-3
	15-48	Silt loam, very fine sandy loam, loam.	CL-ML, ML	A-4	0	100	100	90-100	80-95	<28	NP-7
	48-60	Very fine sandy loam, silt loam, loam.	ML, CL-ML	A-4	0	100	100	90-100	80-95	<28	NP-7
Hebert	0-15	Silt loam	ML, CL-ML	A-4	0	100	100	100	65-100	<27	NP-7
	15-32	Loam, silt loam, silty clay loam.	CL	A-6, A-7-6	0	100	100	100	85-100	31-45	11-22
	32-60	Stratified very fine sandy loam to silty clay loam.	ML, CL-ML, CL	A-4, A-6	0	100	100	90-100	60-100	22-40	3-18
illcu	0-8	Silt loam	CL, CL-ML	A-4, A-6	0	100	100	95-100	85-100	24-30	5-15
	8-40	Silty clay loam, silt loam.	CL	A-6, A-7-6	0	100	100	95-100	90-100	30-42	14-23
	40-76	Silty clay loam, silt loam.	CL	A-6, A-7-6	0	100	100	95-100	85-100	36-46	14-22
:* dalfs.											
ussy	0-4	Silt loam	ML, CL-ML, CL	A-4, A-6	0	100	100	95-100	90-100	<27	NP-12
	4-24	Silt loam, silty clay loam.	CL, CL-ML, ML	A-6, A-4	0	100	100	95-100	90-100	20-35	3-15
	24-60	Silt loam, silty clay loam.	CL, CL-ML, ML	A-6, A-4	0	100	100	95-100	85-95	25-40	3-25
ightsville	0-11	Silt loam	ML, CL, CL-ML	A-4	0	100	95-100	90-100	75-100	<31	NP-10
	11-43	Silty clay, clay, silty clay loam.	CH, CL	A-7	0	100	100	95-100	90-100	41-65	22-40
	43-73	Silty clay loam, silty clay, silt loam.	CL, CH	A-7, A-6	0	100	95-100	95-100	90-100	35-55	16-30
rktown	0-7	Clay	MH, CH, OH	A-7	0	100	100	100	95-100	55-75	24-45
	7-48	Clay	CH	A-7	0	100	100	100	95-100	60-80	32-50
	48-60	Clay	CH	A-7	0	100	100	95-100	90-100	60-80	32-50

* See description of the map unit for composition and behavior characteristics of the map unit.

TABLE 17.--PHYSICAL AND CHEMICAL PROPERTIES OF THE SOILS

[The symbol < means less than; > means more than. Entries under "Erosion factors--T" apply to the entire profile. Entries under "Organic matter" apply only to the surface layer. Absence of an entry indicates that data were not available or were not estimated]

Map symbol and soil name	Depth	Clay	Moist bulk density	Permeability	Available water capacity	Reaction	Shrink-swell potential	Erosion factors K	Erosion factors T	Organic matter
	In	Pct	G/cm3	In/hr	In/in	pH				Pct
Ad-Allemands	0-36	---	0.05-0.25	>2.0	0.20-0.50	3.6-5.5	Low	----	---	30-85
	36-65	45-95	0.25-1.00	<0.06	0.12-0.18	3.6-6.5	High	0.37		
Ba-Bussy	0-4	5-11	1.00-1.60	0.6-2.0	0.22-0.27	4.5-5.5	Low	0.49	3	.5-5
	4-35	15-30	1.30-1.60	0.6-2.0	0.17-0.27	4.5-5.5	Low	0.43		
	35-56	15-30	1.45-1.75	0.06-0.2	0.06-0.13	4.5-5.5	Moderate	0.37		
	56-65	15-30	1.30-1.60	0.2-0.6	0.17-0.22	4.5-6.0	Moderate	0.37		
Db-Debute	0-10	8-18	1.35-1.65	0.6-2.0	0.18-0.22	4.5-6.0	Low	0.49	3	.5-6
	10-32	18-35	1.35-1.65	0.6-2.0	0.18-0.25	4.5-6.0	Moderate	0.43		
	32-70	15-25	1.45-1.85	0.06-0.2	0.06-0.13	4.5-6.0	Moderate	0.32		
De-Debute	0-8	8-18	1.35-1.65	0.6-2.0	0.18-0.22	4.5-6.0	Low	0.49	3	.5-6
	8-27	13-35	1.35-1.65	0.6-2.0	0.18-0.25	4.5-6.0	Moderate	0.43		
	27-90	15-25	1.45-1.85	0.06-0.2	0.06-0.13	4.5-6.0	Moderate	0.32		
Dx-Dexter	0-7	10-27	1.30-1.70	0.6-2.0	0.15-0.24	5.1-6.5	Low	0.43	5	.5-4
	7-48	10-35	1.40-1.80	0.6-2.0	0.15-0.24	4.5-6.0	Low	0.32		
	48-87	10-30	1.30-1.70	0.6-6.0	0.08-0.18	4.5-6.0	Low	0.24		
Fo-Forestdale	0-6	27-38	1.35-1.65	0.2-0.6	0.20-0.22	4.5-6.0	Moderate	0.37	5	.5-4
	6-27	35-60	1.20-1.60	<0.06	0.14-0.18	4.5-6.0	High	0.28		
	27-60	10-35	1.35-1.65	0.2-0.6	0.17-0.22	5.1-7.8	Moderate	0.37		
Fr-Frizzell	0-48	8-19	1.35-1.65	0.6-2.0	0.15-0.22	4.5-5.5	Low	0.49	5	.5-4
	48-54	14-35	1.35-1.65	0.06-0.2	0.15-0.20	4.5-5.5	Low	0.43		
	54-76	14-30	1.35-1.65	0.06-0.6	0.15-0.20	4.5-5.5	Low	0.43		
Ga-Gallion	0-7	14-27	1.35-1.65	0.6-2.0	0.21-0.23	5.6-7.3	Low	0.43	5	.5-2
	7-19	14-35	1.35-1.75	0.6-2.0	0.20-0.22	5.6-7.8	Moderate	0.37		
	19-60	14-35	1.35-1.75	0.6-2.0	0.20-0.23	6.1-8.4	Low	0.37		
Gb-Gallion	0-14	27-35	1.35-1.65	0.6-2.0	0.20-0.22	5.6-7.3	Moderate	0.37	5	.5-2
	14-60	14-35	1.35-1.75	0.6-2.0	0.20-0.22	5.6-7.8	Moderate	0.32		
Gm-Groom	0-5	10-20	1.30-1.65	0.6-2.0	0.18-0.24	3.6-7.3	Low	0.43	5	.5-2
	5-12	18-25	1.35-1.80	0.2-0.6	0.18-0.24	3.6-5.5	Low	0.37		
	12-78	20-35	1.35-1.80	0.2-0.6	0.15-0.24	3.6-5.5	Moderate	0.37		
Go-Groom	0-4	10-20	1.30-1.65	0.6-2.0	0.18-0.24	3.6-5.5	Low	0.43	5	.5-2
	4-14	18-25	1.35-1.80	0.2-0.6	0.18-0.24	3.6-5.5	Low	0.37		
	14-70	20-35	1.35-1.80	0.2-0.6	0.15-0.24	3.6-5.5	Moderate	0.37		
Gp:* Groom	0-5	10-20	1.30-1.65	0.6-2.0	0.18-0.24	3.6-5.5	Low	0.43	5	.5-2
	4-14	18-25	1.35-1.80	0.2-0.6	0.18-0.24	3.6-5.5	Low	0.37		
	14-75	20-35	1.35-1.80	0.2-0.6	0.15-0.24	3.6-5.5	Moderate	0.37		
Mollicy	0-5	10-20	1.35-1.70	0.6-2.0	0.18-0.24	3.6-5.5	Low	0.43	3	.5-2
	5-34	18-35	1.35-1.80	0.2-0.6	0.15-0.22	3.6-5.5	Moderate	0.32		
	34-90	11-35	1.35-1.85	0.2-0.6	0.12-0.20	3.6-5.5	Moderate	0.28		
Gs:* Groom	0-4	10-20	1.30-1.65	0.6-2.0	0.18-0.24	3.6-5.5	Low	0.43	5	.5-2
	4-9	18-25	1.35-1.80	0.2-0.6	0.18-0.24	3.6-5.5	Low	0.37		
	9-65	20-35	1.35-1.80	0.2-0.6	0.15-0.24	3.6-5.5	Moderate	0.37		
Mollicy	0-3	10-20	1.35-1.70	0.6-2.0	0.18-0.24	3.6-5.5	Low	0.43	3	.5-2
	3-34	18-35	1.35-1.80	0.2-0.6	0.15-0.22	3.6-5.5	Moderate	0.32		
	34-70	12-35	1.35-1.85	0.2-0.6	0.12-0.20	3.6-5.5	Moderate	0.28		
Gu-Guyton	0-23	7-25	1.35-1.65	0.6-2.0	0.20-0.23	4.5-6.0	Low	0.43	5	<2
	23-42	20-35	1.35-1.70	0.06-0.2	0.15-0.22	3.6-6.0	Low	0.37		
	42-60	20-35	1.35-1.70	0.06-2.0	0.15-0.22	4.5-7.3	Low	0.37		

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soil survey of
Jim Wells County, Texas

United States Department of Agriculture
Soil Conservation Service
in cooperation with
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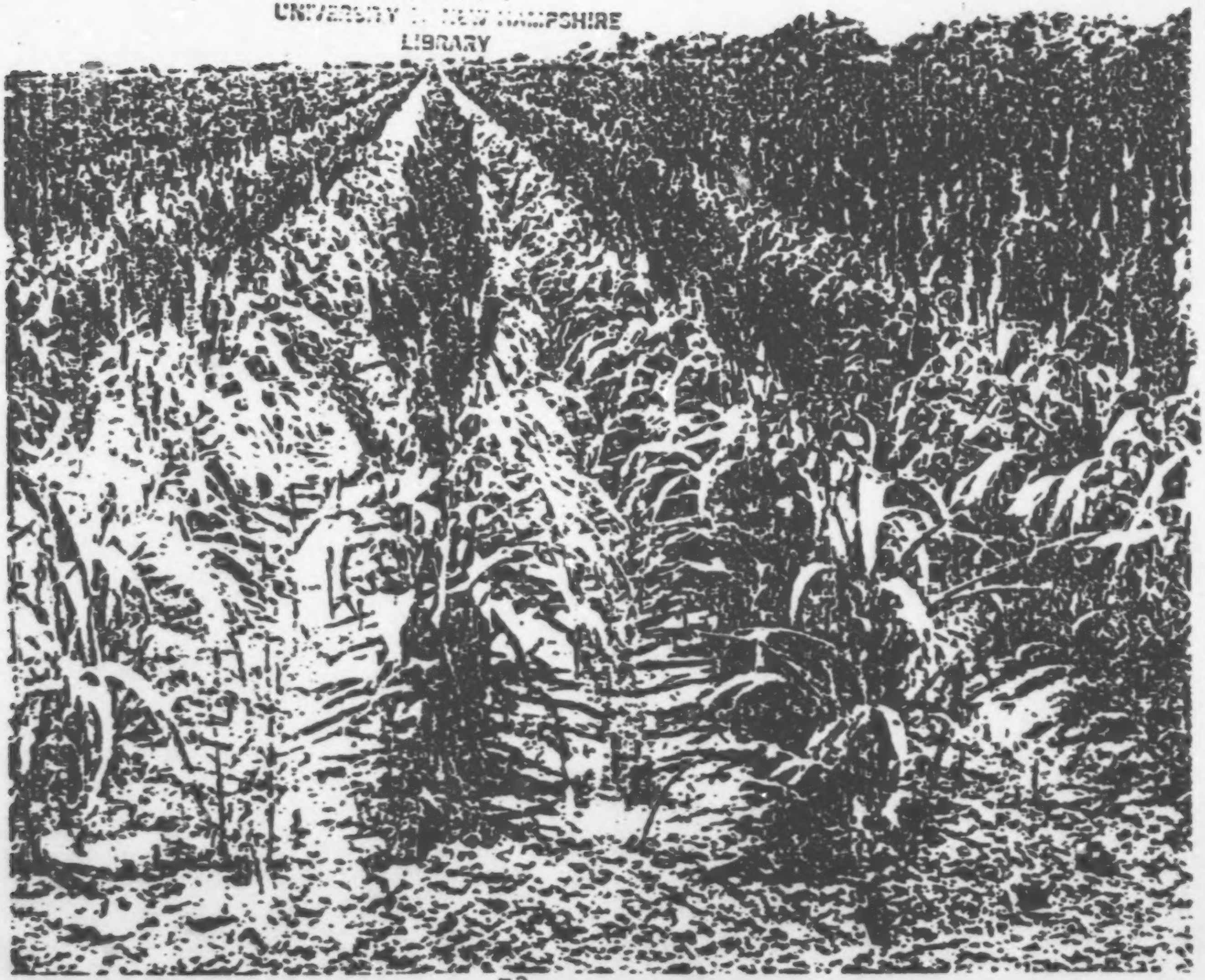

SOIL SURVEY OF JIM WELLS COUNTY, TEXAS

By Fred E. Minzenmayer, Soil Conservation Service

Soils surveyed by Larry F. Ratliff, Guido Frankl, Dan Arriaga, Ramon Garcia, Ben Hajek, Russell Sanders, and Charles M. Thompson, Soil Conservation Service

United States Department of Agriculture, Soil Conservation Service,
in cooperation with Texas Agricultural Experiment Station

JIM WELLS COUNTY is in the southern part of Texas. It covers an area of 542,080 acres, or 847 square miles, of which 1,216 acres is water. Elevation ranges from 100 to 400 feet above sea level. The average annual rainfall is 26.6 inches, mean annual temperature is 72.4 degrees F, and the growing season is 289 days.

Ranching and farming and oil and gas production are important enterprises in the county. About 75 percent of the county, mostly the western and southwestern parts, is nearly level to sloping rangeland and pastureland. About 22 percent, the northern and northeastern parts, is nearly level to gently sloping cropland and pastureland. The rest is urban land and water areas. The main ranching enterprise is raising beef cattle. The main cultivated crops are cotton, grain sorghum, and flax.

The soils of this county formed under grass vegetation and are dominantly dark colored, loamy, and dry. Areas that are not protected are subject to water erosion.

General nature of the county

This section briefly discusses settlement and population, climate, agriculture, natural resources, and geology.

Settlement and population

Jim Wells County was established in 1911. It was named after Judge James B. Wells, a lawyer and political figure of the Fifteenth Congressional District (*5*).

The area was settled in 1748. The settlers were cattlemen from the hills of Andalucia and the semiarid regions of northern Mexico. Many of the cattlemen received their land from grants directly from the King of Spain.

One grant of about 886,000 acres to Enrique Villareal in June 1785 included the territory that later was divided into Nueces and Jim Wells Counties. In 1832, Captain H.L. Kinney bought part of this grant and brought settlers from Europe.

In 1970, the population of the county was 33,032. Alice, the county seat, is in the center of the county and has a population of 20,121 (*3*).

Climate

Jim Wells County has hot summers and fairly warm winters. Cold spells or snowfalls are rare. Rains are usually heaviest late in spring and early in fall. Rain in the fall is often associated with a dissipating tropical storm. Total annual precipitation is usually adequate for range vegetation. But, because of the high rate of evapotranspiration, it often is not adequate for cotton, small grain, and sorghum without supplemental irrigation.

Table 1 gives data on temperature and precipitation for the survey area, as recorded at Alice, Texas, for the period 1951 to 1976. Table 2 shows probable dates of the first freeze in fall and the last freeze in spring. Table 3 provides data on length of the growing season.

In winter the average temperature is 58 degrees F, and the average daily minimum temperature is 45 degrees. The lowest temperature on record, which occurred at Alice on January 12, 1962, is 12 degrees. In summer the average temperature is 84 degrees, and the average daily maximum temperature is 96 degrees. The highest recorded temperature, which occurred on August 8, 1956, is 110 degrees. Freeze dates in spring and fall are given in table 2.

Growing degree days, shown in table 1, are equivalent to "heat units." During the month, growing degree days accumulate by the amount that the average temperature each day exceeds a base temperature (50 degrees F). The normal monthly accumulation is used to schedule single or successive plantings of a crop between the last freeze in spring and the first freeze in fall.

Of the total annual precipitation, 19 inches, or 70 percent, usually falls in April through September, which includes the growing season for most crops. In 2 years out of 10, the rainfall in April through September is less than

This is a publication of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and agencies of the States, usually the Agricultural Experiment Stations. In some surveys, other Federal and local agencies also contribute. The Soil Conservation Service has leadership for the Federal part of the National Cooperative Soil Survey. In line with Department of Agriculture policies, benefits of this program are available to all, regardless of race, color, national origin, sex, religion, marital status, or age.

Major fieldwork for this soil survey was completed in 1974. Soil names and descriptions were approved in 1976. Unless otherwise indicated, statements in the publication refer to conditions in the survey area in 1974. This survey was made cooperatively by the Soil Conservation Service and the Texas Agricultural Experiment Station. It is part of the technical assistance furnished to the Nueces-Jim Wells-Kleberg Soil and Water Conservation District.

Soil maps in this survey may be copied without permission, but any enlargement of these maps could cause misunderstanding of the detail of mapping and result in erroneous interpretations. Enlarged maps do not show small areas of contrasting soils that could have been shown at a larger mapping scale.

Cover: Clareville loam, 0 to 1 percent slopes, is well suited to grain sorghum.

TABLE 16.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS

[The symbol < means less than. Entries under "Erosion factors--T" apply to the entire profile. Absence of an entry indicates that data were not available or were not estimated]

Soil name and map symbol	Depth	Permea-bility	Available water capacity	Soil reaction	Salinity	Shrink-swell potential	Risk of corrosion		Erosion factors	
							Uncoated steel	Concrete	K	T
	In	In/hr	In/in	pH	Mmhos/cm					
Aransas:										
1, 2	0-65	<0.06	0.12-0.18	7.9-8.4	<4	High	High	Low	0.32	5
Clareville:										
3	0-11	0.6-2.0	0.12-0.20	6.6-7.8	<2	Moderate	Moderate	Low	0.32	5
	11-38	0.2-0.6	0.15-0.20	7.4-8.4	<2	High	High	Low	0.32	
	38-64	0.6-2.0	0.12-0.16	7.9-8.4	<4	Moderate	High	Low	0.32	
Comitas:										
4	0-32	2.0-6.0	0.05-0.10	6.1-7.3	<2	Low	Low	Low	0.17	5
	32-75	2.0-6.0	0.11-0.17	6.1-8.4	<2	Low	Low	Low	0.24	
Czar:										
5, 6	0-13	0.6-2.0	0.09-0.15	6.6-7.8	<2	Low	Low	Low	0.24	5
	13-68	0.6-2.0	0.10-0.18	7.4-8.4	<2	Low	Moderate	Low	0.32	
Danjer:										
7, 8	0-6	0.06-0.2	0.15-0.20	7.9-8.4	<4	High	High	Low	0.32	5
	6-65	<0.06	0.12-0.18	7.9-8.4	<4	High	High	Low	0.32	
Delfina:										
9	0-12	2.0-6.0	0.07-0.11	6.6-7.8	<2	Low	Moderate	Low	0.24	5
	12-36	0.2-0.6	0.10-0.20	6.6-8.4	<4	Moderate	High	Low	0.32	
	36-80	0.6-2.0	0.10-0.17	7.4-8.4	<4	Moderate	High	Low	0.32	
10, 11	0-11	2.0-6.0	0.11-0.15	6.1-7.8	<2	Low	Moderate	Low	0.24	5
	11-30	0.2-0.6	0.10-0.20	6.6-8.4	<4	Moderate	High	Low	0.32	
	30-80	0.6-2.0	0.10-0.17	7.4-8.4	<4	Moderate	High	Low	0.32	
Delmita:										
12	0-10	0.6-2.0	0.10-0.14	6.6-7.8	<2	Low	Moderate	Low	0.24	3
	10-30	0.6-2.0	0.12-0.15	6.6-7.8	<2	Low	Moderate	Low	0.28	
	30-32	---	---	---	---	---	---	---	---	
Edroy:										
13, 14	0-18	<0.06	0.10-0.17	7.9-8.4	<8	Very high	High	Low	0.32	5
	18-42	0.06-0.2	0.09-0.17	7.9-8.4	<8	High	High	Low	0.32	
	42-53	0.06-0.2	0.08-0.16	7.9-8.4	<8	Moderate	High	Low	0.37	
	53-72	0.06-2.0	0.05-0.15	7.9-8.4	<8	---	High	Low	0.43	
Goliad:										
15, 16	0-11	2.0-6.0	0.10-0.15	6.6-8.4	<2	Low	Low	Low	0.17	2
	11-15	0.2-0.6	0.15-0.20	6.6-8.4	<2	Moderate	High	Low	0.24	
	15-28	0.2-0.6	0.15-0.20	7.4-8.4	<2	Moderate	High	Low	0.24	
	28-32	---	---	---	---	---	---	---	---	
17, 18	0-11	0.6-2.0	0.12-0.17	6.6-8.4	<2	Moderate	Moderate	Low	0.17	2
	11-15	0.2-0.6	0.15-0.20	6.6-8.4	<2	Moderate	High	Low	0.24	
	15-28	0.2-0.6	0.15-0.20	7.4-8.4	<2	Moderate	High	Low	0.24	
	28-32	---	---	---	---	---	---	---	---	
Lacoste:										
[1]19:										
Lacoste part	0-7	0.6-2.0	0.10-0.15	6.6-8.4	<2	Low	Moderate	Low	0.24	1
	7-12	0.6-2.0	0.11-0.16	6.6-8.4	<2	Low	Moderate	Low	0.28	
	12-15	---	---	---	---	---	---	---	---	
Olmos part	0-9	0.6-2.0	0.05-0.10	7.9-8.4	<2	Low	High	Low	0.10	1
	9-25	---	---	---	---	---	---	---	---	
Lattas:										
20, 21	0-5	0.06-0.2	0.12-0.18	7.9-8.4	<4	High	High	Low	0.32	5
	5-70	<0.06	0.15-0.20	7.9-8.4	<4	High	High	Low	0.32	

See footnote at end of table.

TABLE 16.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS--Continued

Soil name and map symbol	Depth	Permeability	Available water capacity	Soil reaction	Salinity	Shrink-swell potential	Risk of corrosion		Erosion factors	
							Uncoated steel	Concrete	K	T
	In	In/hr	In/in	pH	Mmhos/cm					
ging: 2	0-24	2.0-6.0	0.05-0.10	6.1-7.3	<2	Very low	Low	Low	0.20	5
	24-55	0.06-0.2	0.15-0.20	6.1-8.4	<2	Moderate	High	Low	0.32	
	55-65	0.6-2.0	0.14-0.18	6.6-8.4	<2	Moderate	High	Low	0.32	
guel: 3	0-10	2.0-6.0	0.10-0.15	6.1-7.3	<2	Low	High	Low	0.43	5
	10-33	<0.06	0.14-0.17	6.6-8.4	<2	Moderate	High	Low	0.32	
	33-60	0.06-0.2	0.12-0.15	7.9-8.4	<2	Moderate	High	Low	0.32	
m: 4	0-72	2.0-6.0	0.10-0.16	6.6-8.4	<2	Low	Moderate	Low	0.24	5
1-Waste land: 5	---	---	---	---	---	---	---	---	---	---
sos: 26	0-9	0.6-2.0	0.05-0.10	7.9-8.4	<2	Low	High	Low	0.10	1
	9-35	---	---	---	---	---------	---------	---------	---	
slika: 7, 28	0-4	0.6-2.0	0.11-0.17	6.6-7.8	<2	Low	Moderate	Low	0.37	5
	4-10	<0.06	0.12-0.18	6.6-7.3	<2	Moderate	High	Low	0.43	
	10-60	0.06-0.6	0.10-0.15	7.9-8.4	<4	Moderate	High	Low	0.43	
pagus: 29	0-16	2.0-6.0	0.07-0.11	6.1-7.3	<2	Low	Low	Low	0.24	5
	16-30	0.06-0.2	0.14-0.18	6.1-7.3	<2	High	High	Low	0.32	
	30-65	0.06-0.6	0.12-0.18	7.4-8.4	<2	High	High	Low	0.37	
palote: 3	0-17	2.0-6.0	0.07-0.11	6.1-7.8	<2	Low	Low	Low	0.32	5
	17-41	0.06-0.2	0.13-0.18	6.1-8.4	<2	Moderate	High	Low	0.32	
	41-65	0.06-0.2	0.12-0.17	7.9-8.4	<2	Moderate	High	Low	0.32	
1	0-16	2.0-6.0	0.11-0.15	6.1-7.8	<2	Low	Low	Low	0.32	5
	16-38	0.06-0.2	0.13-0.18	6.1-8.4	<2	Moderate	High	Low	0.32	
	38-65	0.06-0.2	0.12-0.17	7.9-8.4	<2	Moderate	High	Low	0.32	
rrita: 2	0-5	0.6-2.0	0.11-0.16	6.6-8.4	<2	Low	Moderate	Low	0.17	2
	5-9	0.6-2.0	0.12-0.17	6.6-8.4	<2	Moderate	High	Low	0.24	
	9-17	0.2-0.6	0.12-0.18	7.4-8.4	<2	Moderate	High	Low	0.24	
	17-24	---	---	---	---	---------	---------	---------	---	
rnitas: 3	0-10	0.6-2.0	0.11-0.16	7.9-8.4	<2	Low	Moderate	Low	0.20	3
	10-28	0.6-2.0	0.13-0.18	7.9-8.4	<2	Moderate	High	Low	0.28	
	28-61	0.6-2.0	0.10-0.15	7.9-8.4	<2	Low	High	Low	0.32	
4, 35, 36	0-11	0.6-2.0	0.11-0.16	7.9-8.4	<2	Low	Moderate	Low	0.20	3
	11-30	0.6-2.0	0.13-0.18	7.9-8.4	<2	Moderate	High	Low	0.28	
	30-72	0.6-2.0	0.10-0.15	7.9-8.4	<2	Low	High	Low	0.32	
ttus: 7, 38, 39	0-17	0.6-2.0	0.10-0.15	7.9-8.4	<2	Low	Moderate	Low	0.24	2
	17-21	0.6-2.0	0.02-0.05	7.9-8.4	<2	Very low	Moderate	Low	---	
	21-65	0.6-6.0	0.08-0.12	7.9-8.4	<2	Low	Moderate	Low	0.24	
arr: 0, 41, 42, 43	0-9	0.6-2.0	0.09-0.17	7.9-8.4	<4	Low	High	Low	0.24	5
	9-65	0.6-2.0	0.09-0.17	7.9-8.4	<4	Low	High	Low	0.32	
ts: 4	---	---	---	---	---	---	---	---	---	---

See footnote at end of table.

APPENDIX E

ANALYSIS OF ENGINEERED CONTROLS OF SUBTITLE C FACILITIES FOR LAND DISPOSAL RESTRICTIONS DETERMINATIONS

REVISED DISTRIBUTION OF LEACHING RATES

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4.0	CONCLUSIONS	4-1
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1.0 INTRODUCTION

As part of recent federal legislation, the U.S. Environmental Protection Agency (EPA) must review all listed hazardous wastes and determine which wastes should be banned from land disposal facilities. The general approach for identifying such wastes was developed by EPA's Office of Solid Waste (OSW). OSW's analytical procedure includes credits for engineering controls that are designed into Subtitle C facilities. These engineering controls are used to determine leaching rates from Subtitle C facilities based on long-term performance (e.g., beyond anticipated design life). An analysis of leaching rates from Subtitle C facilities and Subtitle D facilities was performed and reported in June and August of 1985 (Jordan, 1985). Jordan's analysis evaluated 18 climatic centers throughout the contiguous 48 states. Recommendations for future studies included 1) an increase in the number of cities evaluated; and 2) comparing leaching rates based on the 5-year HELP[1] model data base to a long-term (i.e., 20-years) precipitation data base. This report presents the results of the additional analyses conducted in accordance with those recommendations.

---

[1] Hydrologic Evaluation of Landfill Performance (Schroeder, et. al., 1984)

2.0 REVISED LEACHING RATE DISTRIBUTIONS

2.1 Analytical Approach

The analytical approach used for this evaluation is identical to that used in the June 1985 study in which a standard set of design and long-term conditions was used to estimate the leaching rates for Subtitle C and D facilities. In both studies these standard sets, along with climatological data, were entered into the HELP model resulting in a calculated leaching rate.

2.2 Climatic Data Base

In the June 1985 study a total of 18 climatic centers were identified for developing the national leaching rate distribution. As fifty percent of these locations yielded leaching rates of less than one inch for Subtitle C facilities, few data points were provided to establish the upper end of the leaching rate. To obtain more data for the higher leaching rates, 12 additional climatic centers with precipitation averages of greater than 20 inches were evaluated in the September 1985 study. The combined list of cities selected for evaluation is presented in Table 2-1. Included in the group are cities with an extended data base of up to 20 years that were also used for a sensitivity analysis (Section 3.0) of the leaching rate based on a comparison of the 5-year and 20-year climatic data.

TABLE 2-1

LEACHING RATES SUMMARY[a]

PRECIPITATION RANGE[b]	EVAPORATION POTENTIAL	LEACHING RATE[b] "C"	LEACHING RATE[b] "D"	CLIMATOLOGICAL CENTER	AVERAGE 5-YEAR PRECIPITATION[b] (20-YEAR)	PERCENT OF TOTAL AREA[c]
<10	Low	0.0	0.1	Pocatello, ID	9.8	3
	Medium	0.0	0.3	Cedar City, UT	9.8	2
	High	0.0	0.2	Las Vegas, NV	5.3	3
10-20	Low	0.0	0.8	Great Falls, MT	17.9	3
	Medium	0.0	0.6	Rapid City, SD	15.4	13
	Medium	0.02(0.04)	0.04	Denver, CO	13.0 (14.9)	5
	High	0.4	1.2	Midland, TX	16.3	11
20-32	Low	0.3	1.5	St. Cloud, MN	25.8	7.8
	Low	3.1 (3.4)	3.4	Milwaukee, WI	34.1 (33.1)[d]	2.2
	Medium	3.4	3.4	San Francisco, CA	(19.7)	2
	Medium	0.5	1.5	Grand Island, NE	22.2	2
	High	0.5	2.4	Oklahoma City, OK	30.4	5
32-40	Low	3.6	7.2	Montpelier, VT	34.5	3
	Medium	3.7	6.8	Cleveland, OH	36.7	2
	Medium	2.7	5.4	E.St.Louis, IL	36.2	3
	High	2.9	4.8	Columbia, MS	37.1	3
40-48	Low	7.0	12.1	Boston, MA	40.9	0.4
	Low	6.6	12.8	Providence, RI	46.7	0.1
	Low	4.6 (5.3)	10.0	Hartford, CT	41.1 (44.1)	0.2
	Low	5.5	14.2	Worcester, MA	46.5	1.6
	Low	5.7	13.0	Portland, ME	45.5	0.8
	Medium	(5.2)		Newark, NJ	(40.4)	0.3
	Medium	6.6	10.6	Philadelphia, PA	43.7	1.4
	Medium	3.3	6.8	Indianapolis, IN	40.3	5.2
	High	2.5	5.8	Charleston, SC	48.3	4.6
	High	6.4	11.4	Norfolk, VA	44.4	0.4
>48	Low	11.9	35.9	Astoria, OR	65.6	2
	Medium	7.1	12.2	Knoxville, TN	48.1	3
	High	6.9	12.1	Tallahassee, FL	68.4	5
	High	9.8(5.9)	16.7	New Orleans, LA	70.1(56.7)	5

---

[a] Based on USEPA HELP model estimates. Estimates for Subtitle C facilities assume an evapotranspiration zone of 36 inches and 24 inches for Subtitle D facilities.

[b] Inches per year (assumes unit area); number in parenthesis indicates average based on 20 year database.

[c] Percent of total area of contiguous 48 states.

[d] 11 years of precipitation data.

2.3 Leaching Rate Distribution

In both studies leaching rates for Subtitle C and Subtitle D landfill facilities were estimated with the HELP model. Leaching rates were estimated in the September 1985 study for 30 climatic centers in the contiguous 48 states. A summary of the leaching rates is provided in Table 2-1. This information is expressed as percent of area in the contiguous 48 states where leaching rates may be expected to equal or be less than the rate shown.

The distributions of the leaching rates shown on Figure 2-1 do not indicate a significant change from the June 1985 distribution. The maximum leaching rates for Subtitle C and D facilities repeated the pattern of the initial study in that the Subtitle C leaching rates were generally 50 percent less than those for Subtitle D facilities. The distribution represents the estimated leaching rates based on the 5-year precipitation data base with the exception of New Orleans (Louisiana), San Francisco (California) and Newark (New Jersey) which were based on a more extensive data base. The 5-year precipitation data for New Orleans is substantially greater than the 20-year average (70.1 inches versus 56.7 inches); therefore, the 20-year leaching rate was selected to estimate long-term conditions. San Francisco and Newark were not available in the 5-year data base, but estimated leaching rates for both cities are presented using the 20-year data base.

With the inclusion of the 12 additional climatic centers, the greatest change in the leaching distributions was observed for Subtitle D facilities with estimated leaching rates greater than 7 inches. The leaching distribution from

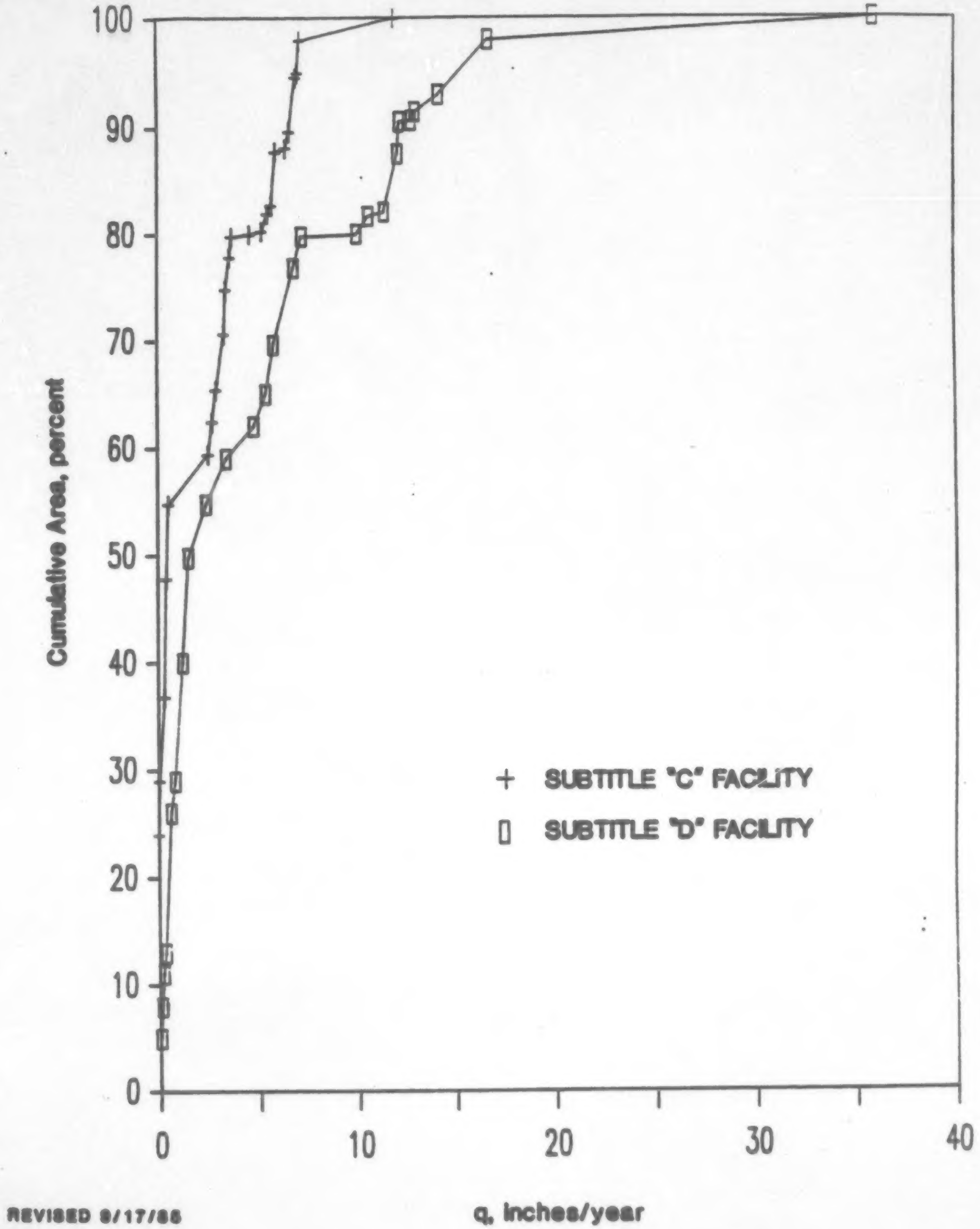

FIGURE 2-1
ESTIMATED DISTRIBUTION OF UNIT AREA LEACHING RATES FOR SUBTITLE C AND D FACILITIES

E.C.JORDAN CO.

that point is shifted to the right an average of 35 percent compared to the previous distribution submitted in August 1985. While the Subtitle C distribution did not change to any extent, the additional data more clearly defines the 4 to 7 inches/year rate range in estimated leaching rates.

3.0 COMPARISON OF 5-YEAR AND 20-YEAR PRECIPITATION DATA

A 5-year precipitation data base is typically used in the HELP model. Jordan's initial comparison provided a sensitivity to the duration of precipitation used in the HELP model based on a comparison of average annual precipitation for 5 years and 30-years of record. The assessment concluded that the HELP model would tend to over-estimate the long-term performance of land disposal facilities by an unknown percentage.

In the September 1985 study, to analyze sensitivity of leaching rates to duration of precipitation, a 20-year data base consisting of eight cities was loaded into the HELP model. The data base was obtained from the Waterways Experiment Station, U.S. Army Corps of Engineers. Half of the cities loaded were not in the original 5-year HELP data base, therefore the nearest climatic center was used to allow a comparison of leaching rates. However, for three cities the nearest climatic center was not appropriate and only five cities were finally used in the analysis. The cities are listed in Table 3-1.

Comparison of the two annual precipitation averages (5-year and 20-year) for each city showed differences ranging from 1 percent to 19 percent (Table 3-1). In contrast to the June 1985 findings, the largest difference occurred in the highest precipitation range, greater than 48 inches. In this case the 5-year average was considerably greater than the 20-year average. The remaining differences were not significant in relation to the range of precipitation.

TABLE 3-1
COMPARISON OF 5 AND 20-YEAR CLIMATOLOGICAL DATA BASE

PRECIPITATION RANGE	EVAPORATION POTENTIAL	CLIMATOLOGICAL CENTER	AVERAGE PRECIPITATION[1]		PERCENT DIFFERENCE	LEACHING RATE "C"[1]		PERCENT DIFFERENCE
			5 YR.[2]	20 YR.		5 YR.	20 YR	
10-20	Medium	Denver, CO	13.0	14.9	15	0.02	0.04	100
20-32	Low	Milwaukee, WI	34.1[3]	33.1[4]	3	3.1	3.4	9
40-48	Low	Hartford, CT	41.1	44.1	7	4.6	5.3	15
>48	Low	Seattle, WA	35.6	35.8	1	8.1	8.7	11
	High	New Orleans, LA	70.1	56.7	19	9.8	5.9	40

Notes:
1. Inches per year (assumes unit area).
2. Based on HELP model, May 1985.
3. Nearest climatic center Chicago.
4. 11 years of precipitation data.

A HELP model was run for the 5-year and 20-year data bases utilizing standard conditions for Subtitle C facilities. The results of the 5-year and 20-year leaching rates, shown on Table 3-1, showed differences ranging from 9 percent to 100 percent. However, the difference of 100 percent occurred in the lowest precipitation range and is not considered a significant increase. The next largest difference, 40 percent for New Orleans, is considered significant as it occurred in the highest precipitation range. In contrast to the initial findings, the 5-year leaching estimate for New Orleans is greater than the long-term average. Generally, the remaining data agree with our original findings that the 5-year data base will tend to over-estimate the long-term performance of land disposal facilities.

The results of the additional study point to an apparent relationship between the percent differences of the precipitation and leaching rates in that the percent difference of the leaching rate appears to be approximately twice the percent difference of the precipitation data for moderate to high precipitation areas.

4.0 CONCLUSIONS

The evaluation of 12 additional climatic centers yielded distributions of leaching rates (Figure 2-1) very similar to the original distribution presented in the June 1985 study. In both studies the Subtitle C distribution yielded leaching rates that were always less, generally 50 percent, than the Subtitle D leaching rates. The inclusion in the September 1985 study of additional climatic centers did provide better definition of the leaching curves for the moderate precipitation ranges.

Comparison of 5-year and 20-year climatological data bases for the moderate to high rainfall ranges indicated a general correlation between the precipitation and leaching rate differences: the percent difference of the 5-year and 20-year leaching rate is approximately twice the percent difference of the 5-year and 20-year precipitation averages. Using this assumption, a review of the percent differences of the 5-year and 30-year average precipitation data presented in Table A-1 of the June 1985 report shows that the percent differences for the rainfall ranges greater than 20 inches are very small. This would indicate that the 18 climatic centers chosen for the initial study are appropriate for use in determining the national leaching distribution rates for Subtitle C facilities.

REFERENCES

E.C. Jordan Co., June 1985. "Analysis of Engineered Controls of Subtitle C Facilities for Land Disposal Restrictions Determinations." EPA Contract No. 68-01-7075. Revised August 1985.

Schroeder, P.R., et al., 1984. "The Hydrologic Evaluation of Landfill Performance (HELP) Model: Volume I - User's Guide for Version I and Volume II - Documentation for Version I." EPA/530-SW-84-009 and -010, U.S. Environmental Protection Agency, Washington, D.C.

DRAFT

APPENDIX F

Analysis of the "Infinite Source" Assumption Used in the Groundwater Model for Land Disposal Banning Evaluation

by

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A key assumption of the ground water fate and transport model is that the mass of each individual Chemical constituent deposited in the facility is sufficiently large to justify the mathematical assumption of an infinite source. In addition to the mathematical convenience resulting from such an assumption, the desire to regulate on leachate concentration values rather than total waste characteristics (e.g., mass loading to the facility) makes the assumption appealing. The purpose of the following analysis is to evaluate the physical significance of the "infinite source" assumption and its impact on the outcomes of the ground water model. The results demonstrate that the "infinite source assumption" of the model is a physically realistic part of the approach and not overly conservative.

The groundwater fate and transport equations are solved for the steady-state case which requires an evaluation of the solution at infinite time. Obviously, the source term under these conditions must also be infinite. The resulting solution allows the plume to fully develop in the groundwater system and the desired maximum concentration at the plume centerline along the x-axis (see Figure 1) is achieved. A useful graphical depiction as C_{LEACH} is the assumed, constant, and infinite source term that produces the down-gradient exposure concentration, C_{ADI}. The time period, Ψ_t is the travel time to the downgradient exposure point and is the approximate time required for the plume shown in Figure 1 to fully develop. The result for the infinite source of leachate is represented by Figure 2. The difference between C_{ADI} and C_{LEACH} results from the combined effects of dispersion, dilution from recharge, and degradation.

The corresponding result for a finite source of the leachate is represented by Figure 3. This results in a pulse input moving through the groundwater system. Depending on the duration of the pulse, the downgradient exposure concentration value (set to the fix value of C_{ADI} in the rule) may be different than that given by the solution in Figure 2. In any case, the duration of the exposure value, Ψ_e, is largely determined by the duration of the pulse input, Ψ_i. The differences between exposure and C_{LEACH} are also related to dispersion, dilution and degradation, but their relative effects may be different than that from the infinite source case. If the input duration is short (i.e., Ψ_i is small), corresponding to a relatively small amount of mass available for transport, then the down-gradient concentration may not reach the levels obtained for the infinite source case. If the input duration is sufficiently long, corresponding to a relatively large amount of mass available for transport, then the down-gradient value will reach the same level as in the infinite source case albeit for a finite period of time, Ψ_e, and the assumption of an infinite source is most likely to be met. The exact mathematical solution for the pulse-load case and its sensitivity to the pulse input time, Ψ_i, is not now implemented for the decision rule. We can, however, approximate the impact of the pulse duration via the steady-state solution by noting that this will yield the maximum values for the down-gradient concentration in the pulse load case.

Another useful characteristic shown in Figure 3 is the exposure time, Ψ_e. Because the reference dose masses for carcinogens are based upon a seventy-year life span it follows that a minimum value for Ψ_e is 70 years. Simply stated, the idea is that the leachate must be emitted at a minimum for a time sufficient to produce the 70-year exposure period. Full development of the plume may or may not actually be achieved depending on the value for Ψ_t. If $\Psi_e >> \Psi_t$ then the plume is fully developed, the requirements for the steady-state solution are met, and a pulse

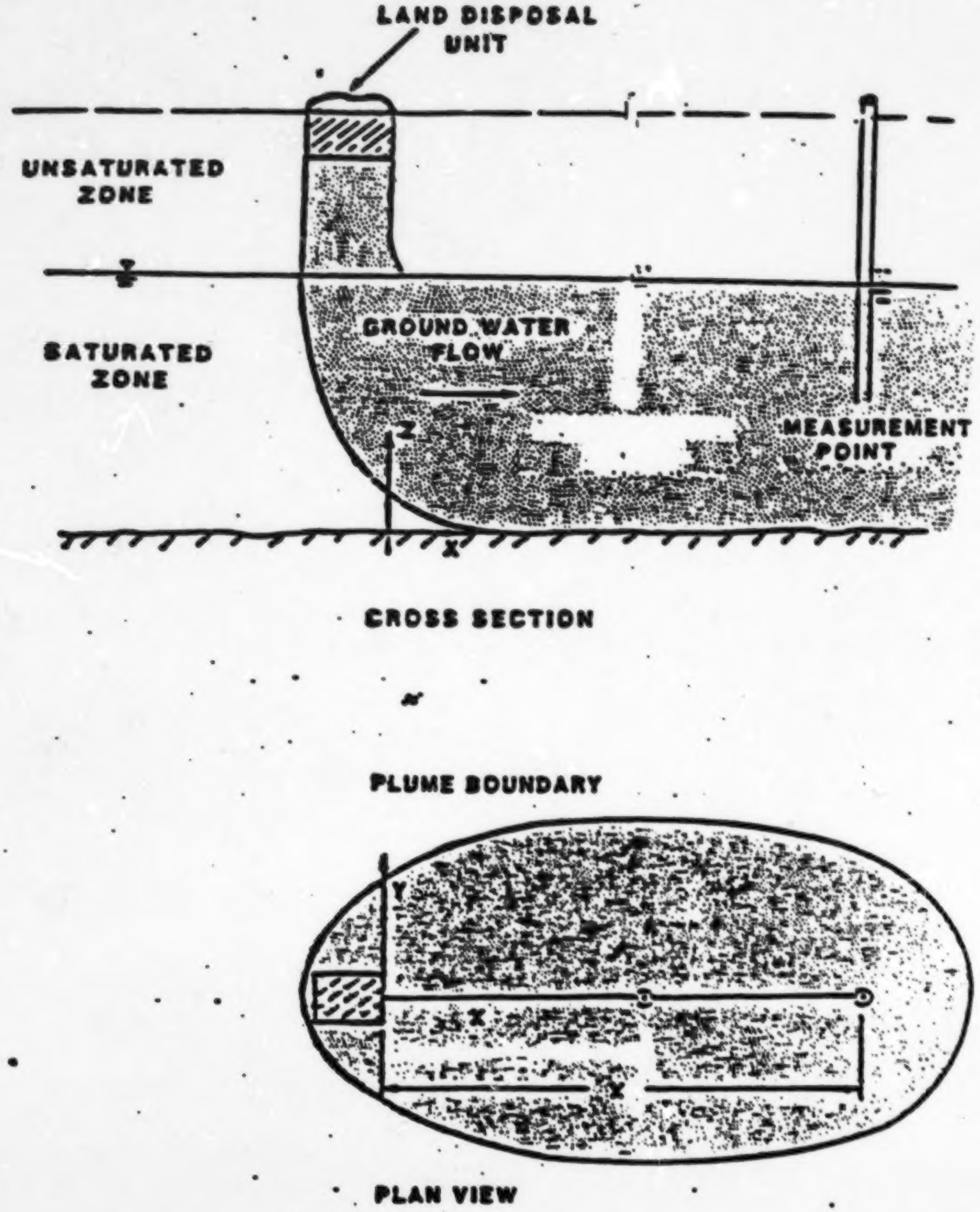
LAND DISPOSAL UNIT
UNSATURATED ZONE
SATURATED ZONE
GROUND WATER FLOW
MEASUREMENT POINT
Z
X
CROSS SECTION
PLUME BOUNDARY
Y
X
X
PLAN VIEW

Figure 1. Schematic description of contaminated groundwater system.

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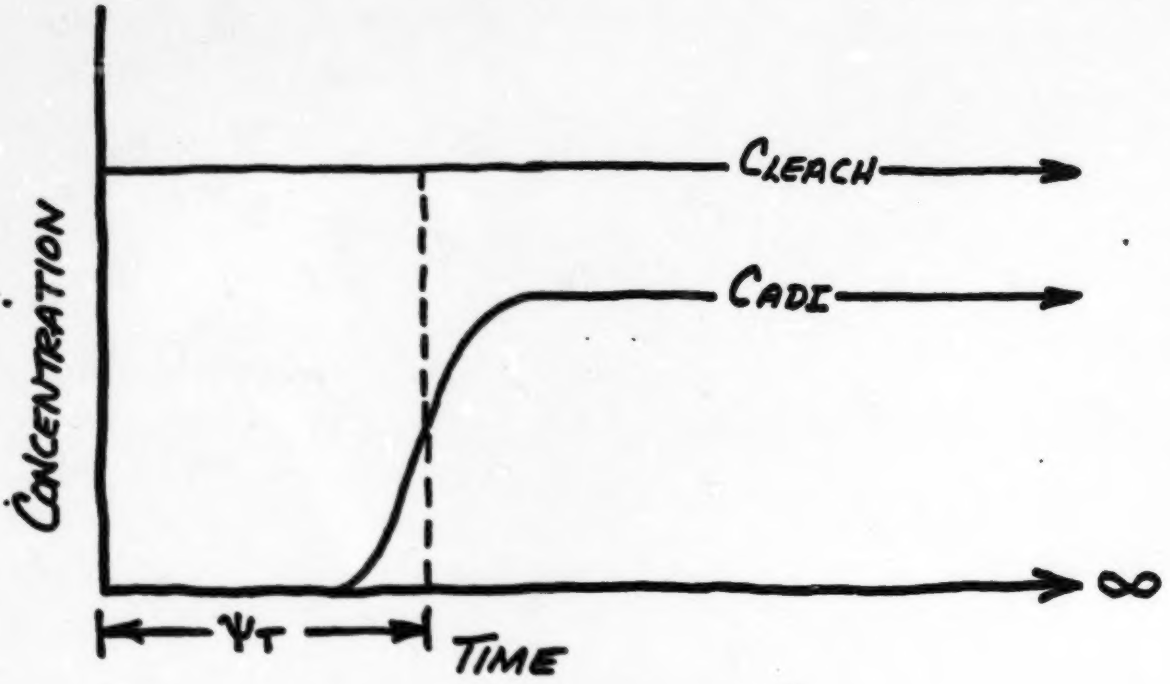

FIGURE 2 TIME HISTORY OF CONCENTRATIONS WITH AN INFINITE SOURCE

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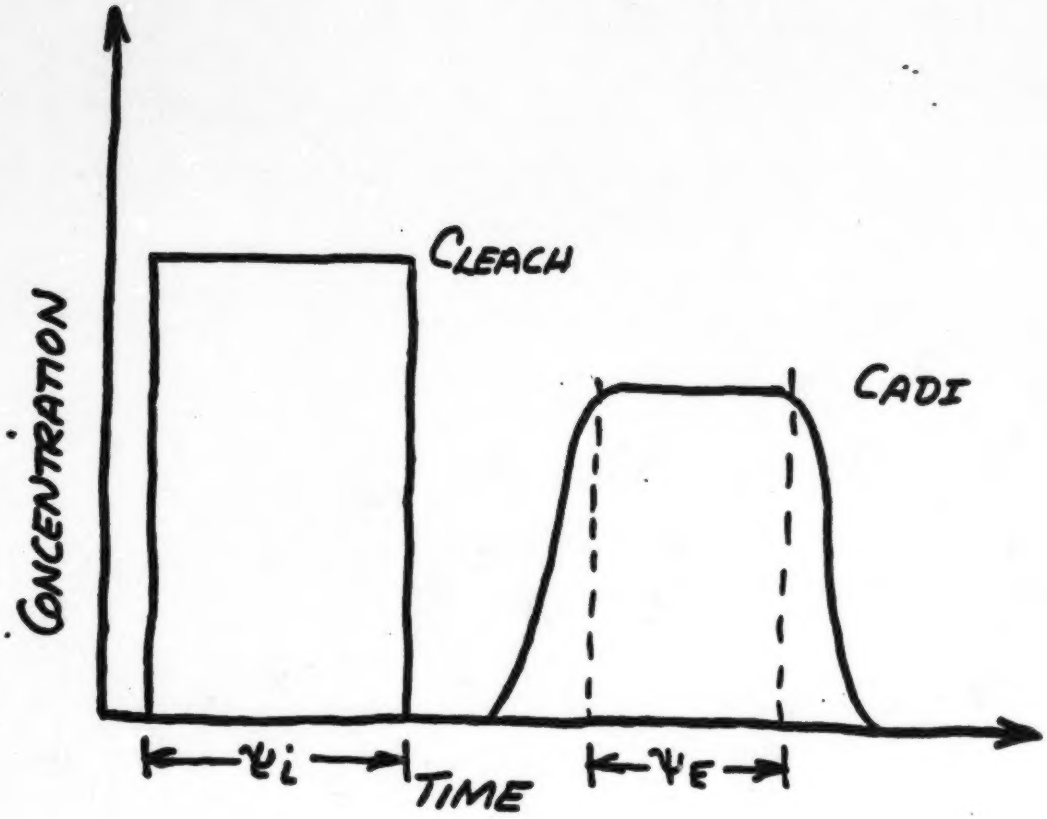

FIGURE 3 TIME HISTORY OF CONCENTRATIONS WITH A FINITE SOURCE

load of duration, Υ_e, can be accurately evaluated via the current model. If $\Upsilon_e \leq \Upsilon_t$ (or perhaps Υ_e somewhat greater than Υ_t) then the pulse or wave concentration observed at the downgradient point may be somewhat less than that predicted by the current solution. It remains useful, however, to use the steady-state equations to yield the maximum values for the down-gradient concentrations.

The above discussion suggests that for purposes of estimating the source mass required for an accurate implementation of the decision rule, two leaching durations are of interest. The time to fully develop the plume, Υ_t, is useful because this determines the absolute minimum time required for the solutions to the equations to be exact. The exposure time, Υ_e, is also important because if insufficient mass is available to produce the C_{ADI} value for this time period then the toxicological assumptions of the health-based thresholds are violated. Thus, for any specific set of conditions in a monte carlo run of the model, we can calculate a mass corresponding to both these time durations.

- The mass leaving the facility during time period, , is calculated as,

$$SM = Q * A_w * C_L * \Upsilon * 10^{-3} \qquad (1)$$

where Q = leachate volume flux, m/yr

A_w = facility area, m^2

C_L = leachate concentration, mg/l

Υ = time duration of leak or emission, yr

SM_{D_Υ} = available mass of constituent, kg

Recall from the solution of the groundwater model that we can express C_L as

$$C_L = C_{ADI}/CD \qquad (2)$$

where C_{ADI} = concentration corresponding to the health-based threshold, mg/l

CD = dimensionless "back-calculated" solution to the groundwater equation

Substitution of (2) into (1) yields

$$SM_\Upsilon = 10^{-3} * Q * A_w * \Upsilon * C_{ADI}/CD \qquad (3)$$

Equation (3) can now be used to calculate the total mass of each specific chemical constituent required to be present in the waste material for any time, , of interest.

A more useful measure of the mass corresponding to the time periods depicted in Figure 2 and 3 is concentration in the waste. That is, the concentration of each constituent of the waste that if made totally available for leaching would produce a sufficient mass of material at the leachate concentation, C_{LEACH}, to yield the exposure values, C_{ADI}. Consider the mass of the waste, MW, in the facility. By combining this total waste mass with the constituent mass expression from equation (3), we obtain

$$\frac{SM}{MW} = \frac{Q * A_W * \Psi * C_{ADI}}{CD * DW * \rho_W * A_W}$$

or

$$LWC = Q * \Psi * C_{ADI}/CD * DW * \rho_W \quad (4)$$

where LWC_{Ψ} = leachate concentration of the constituent in the waste material for leach time, Ψ, mg/kg

DW = depth of the waste material in the facility, m

ρ_W = density of the waste material, gm/cm^3

Equation (4) requires two new parameters not heretofore needed. Fortunately, both will vary over relatively narrow ranges and can be either fixed at mean values or can be allowed to vary according to some distribution. Interestingly, the facility area (which varies widely) cancels in the equation and does not influence the result except through the values for CD taken from the groundwater model.

Equation (4) enables us to calculate for any desired value of CD (say that corresponding to the 90th percentile level) the required concentration level in the waste (assuming all can be leached) for any given duration, Ψ. Recall that at the minimum Ψ must be 70 years. Thus, a minimum waste concentration for any constituent is given by

$$LWC_{min} = 70 * Q * C_{ADI}/CD * DW * \rho_W \quad (5)$$

The value obtained from equation (5) can be viewed as the minimum constituent concentration in the waste (assuming it is all leachable) required to insure that the conditions represented by the ground water model are physically possible. If the actual concentration is greater than LWC_{min}, then the outcome of the ground water model is also physically possible. If the actual concentration is less than LWC_{min}, then the ground water model overestimates the downgradient concentration because the assumed source term is greater than the waste can provide.

Another useful waste characteristic to consider is the concentration of constituent required to fully develop the plume corresponding to the travel time, Υ_t. This value can be determined from

$$\Upsilon_t = X\ (1 + K_D\ \rho_B/\theta)/V \qquad (6)$$

where X = distance downgradient to the exposure point, m

KD = partition coefficient, cm^3/gm

ρ_B = soil bulk density, gm/cm^3

θ = porosity, cm^3/cm^3

V = groundwater flow velocity, m/yr

By combining equation (6) and (4) we obtain

$$LWC_T = C_{ADI} * Q * X(1 + K_D\ \rho_B/\theta)/V * CD * DW * \rho_w \qquad (7)$$

where LWC_T can be interpreted as the minimum constituent concentration in the waste required to insure that the decision rule outcome is derived from a fully developed plume. If the actual waste concentration is greater than LWC_T, then the assumptions become more nearly those of an infinite source and the rule outcomes are accordingly correct. If the actual waste concentration is less than LWC_T, then the plume is not fully developed and the source is exhausted before the downgradient concentration, C_{ADI}, is reached. Note also that if

$$X(1 + K_D\ \rho_B/\theta)/V < 70 \qquad (8)$$

then the minimum exposure time of 70 years will not be achieved by exposure to the mass resulting from the fully developed plume. Thus, LWC_T only has meaning if the travel time is given by equation (6) is greater than 70 years.

Consideration of equations (1)-(8) leads to a useful additional concept in regulating land disposal via leachate concentrations. We can now specify for any given allowable leachate level the associated minimum applicable constituent concentration given as

$$\text{Max}\ [LWC_{min}, LWC_T]$$

This value can be interpreted as the constituent waste concentration below which land disposal is acceptable regardless of the results from the leach test. These values can be viewed as bench-mark measures of the reasonableness of the infinite source assumption embedded in the decision rule.

The problem remains to calculate the LWC_{min} and LWC_T values for any percentile level chosen from the frequency distribution generated by the monte carlo runs. Note from equations 5 and 7 that each monte carlo run (i.e., single values for each variable and parameter in the model) will have a unique set of values for all defined variables except the two new waste parameters, DW and ρ_W. Thus, if these are known we can calculate LWC_{min} and LWC_T values for each data point on the curve and hence the one ultimately chosen for regulation. Example calculations for a non-degrading, sorbing constituent (KOC = 1000.0) with an assumed facility depth of 5 meters, a waste density of 1.0 and C_{ADI} of 1.0 are given in the attached figures. Subtitle C facility results are presented in Figure 4-7 and Subtitle D facility results are presented in Figures 8-11.

The figures demonstrate several important outcomes. First, the magnitudes of both concentration levels (LWCMIN, LWCTOT) and the required masses (SMMIN, SMTOT) are quite reasonable and thus the "infinite source" assumption of the model remains a physically realistic part of the approach. For example, at the 90th percentile level for the Subtitle C facility, LWCMIN ranges from 7-90 mg/kg and SMMIN ranges from 500-50,000 kg if the reference dose is 1.0 mg/l.

Second, pursuing further the ideal of specifying an additional "critical value," the figures suggest that if the 90th percentile is chosen for regulation one can further state that if the constituent concentration in the waste is less than 7 mg/kg then land disposal is safe regardless of the leachate test values.

DRAFT

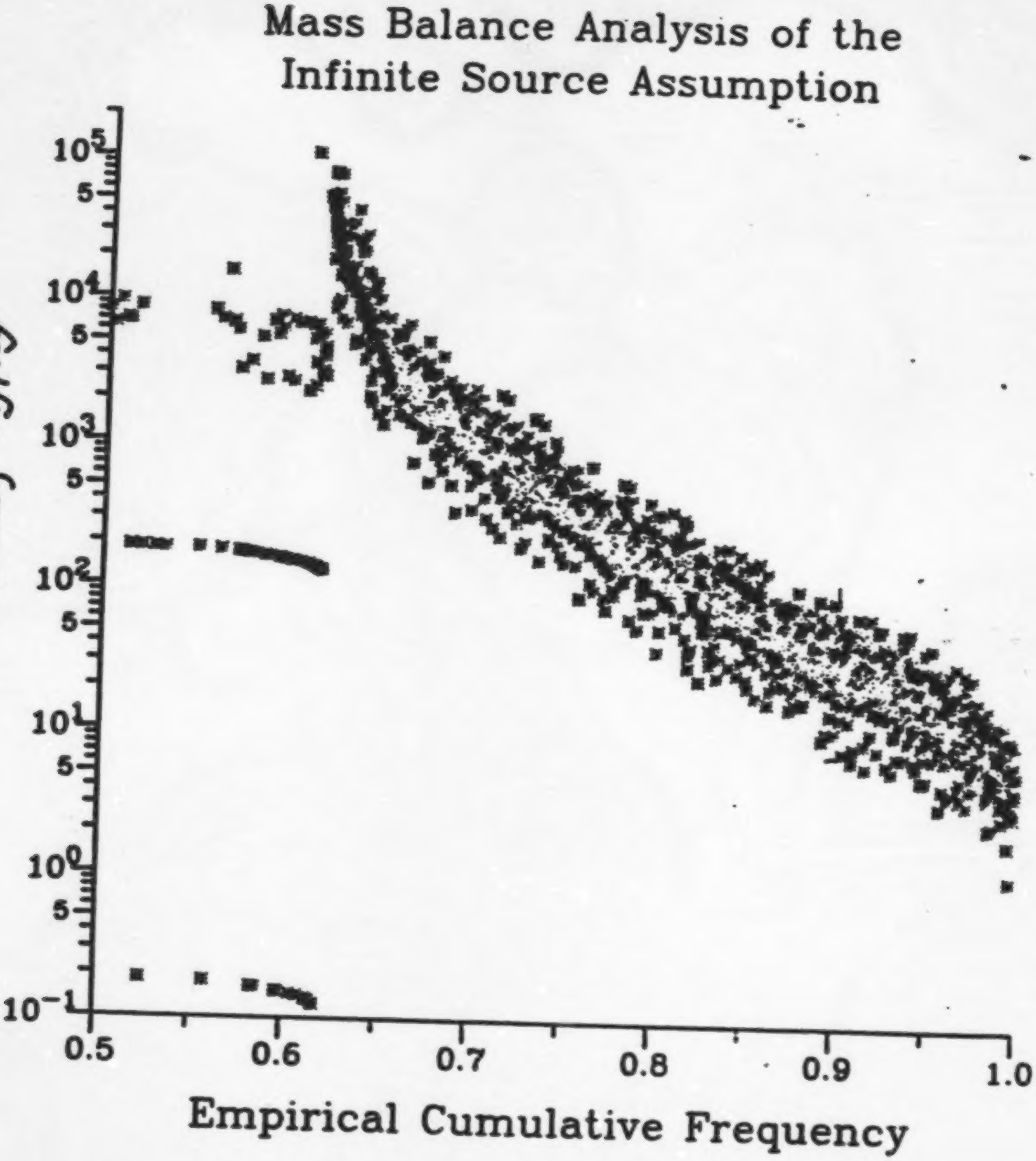

Figure 4. Minimum Applicable Concentration of Constituent in Waste for an Exposure Duration of 70 years

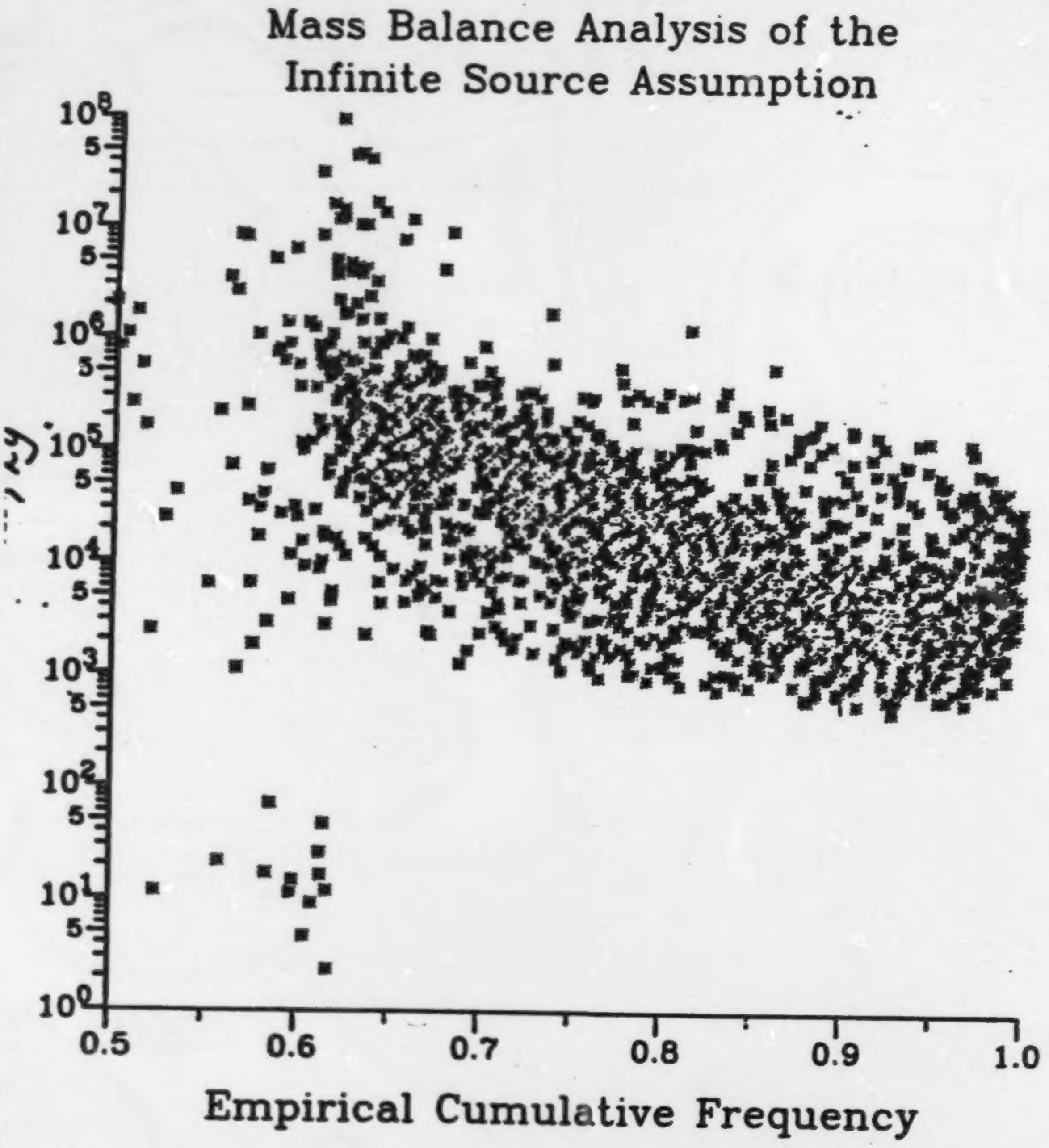

Figure 5. Minimum Mass of Constituent Required in Facility to Produce 70-year Exposure

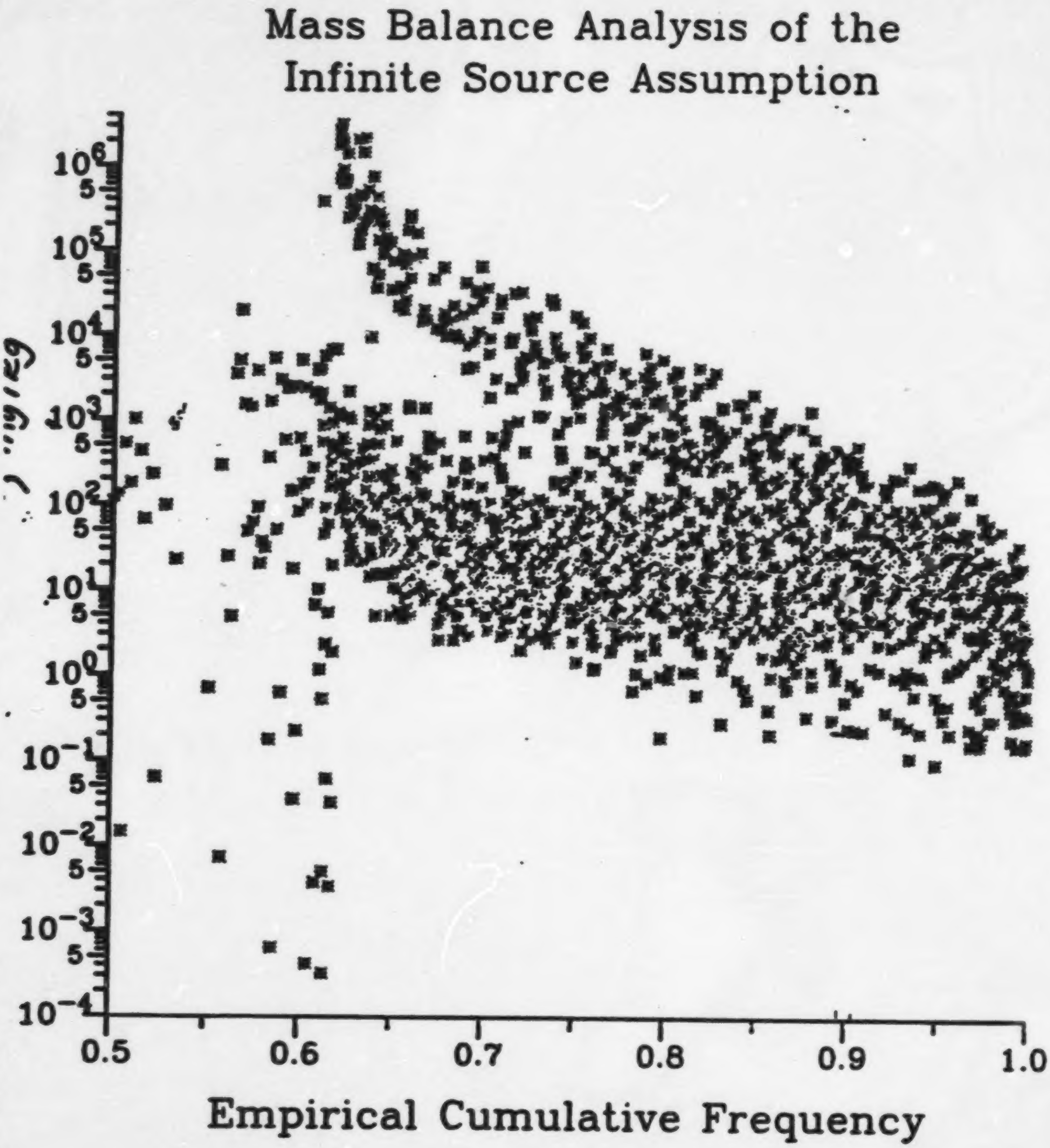

Figure 6. Minimum Concentration of Constituent in Waste Required to Produce Full Development of Groundwater Plume

DRAF

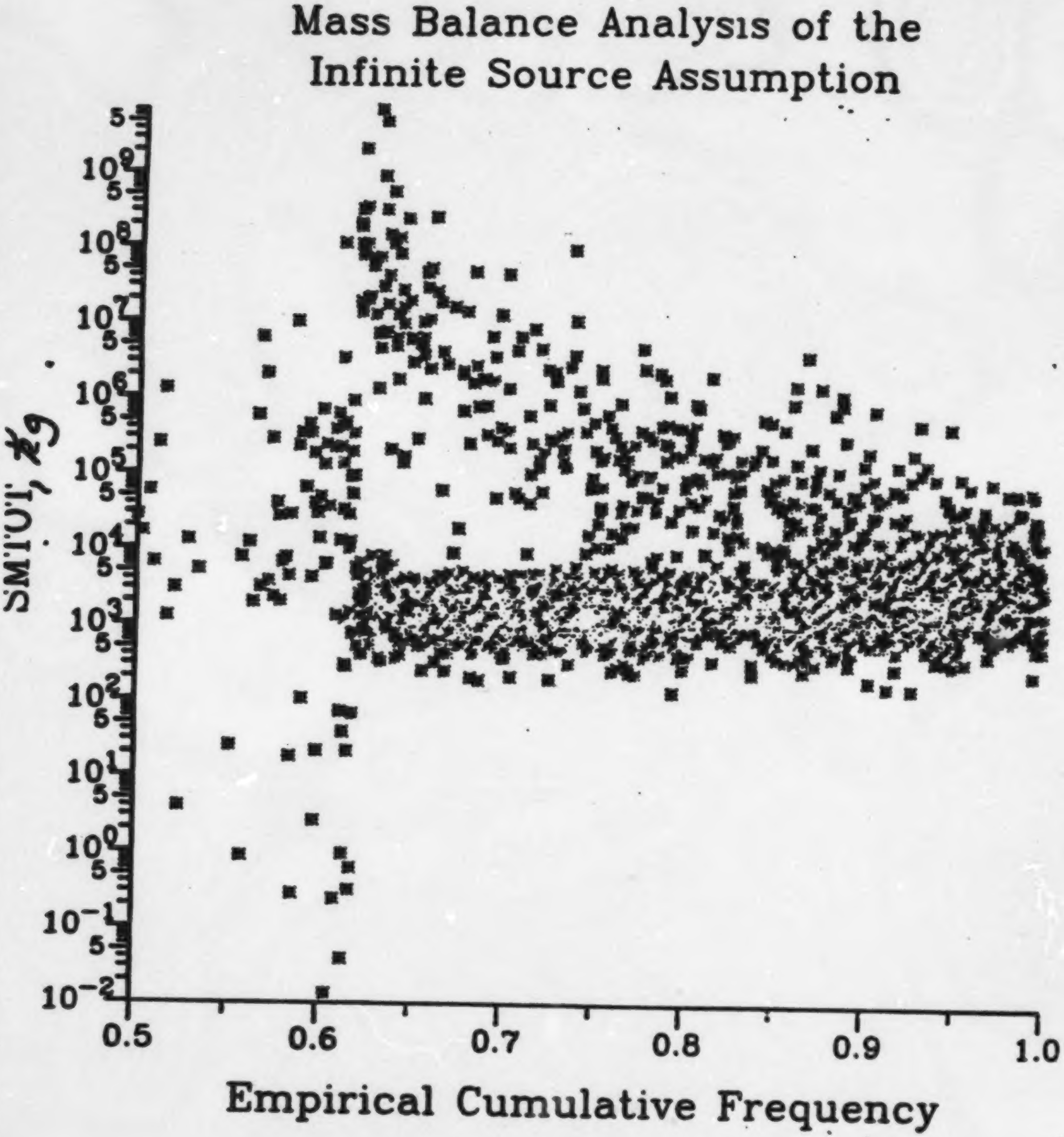

Figure 7. Minimum Mass of Constituent Required in Facility to Produce Fully Developed Groundwater Plume

DRAFT

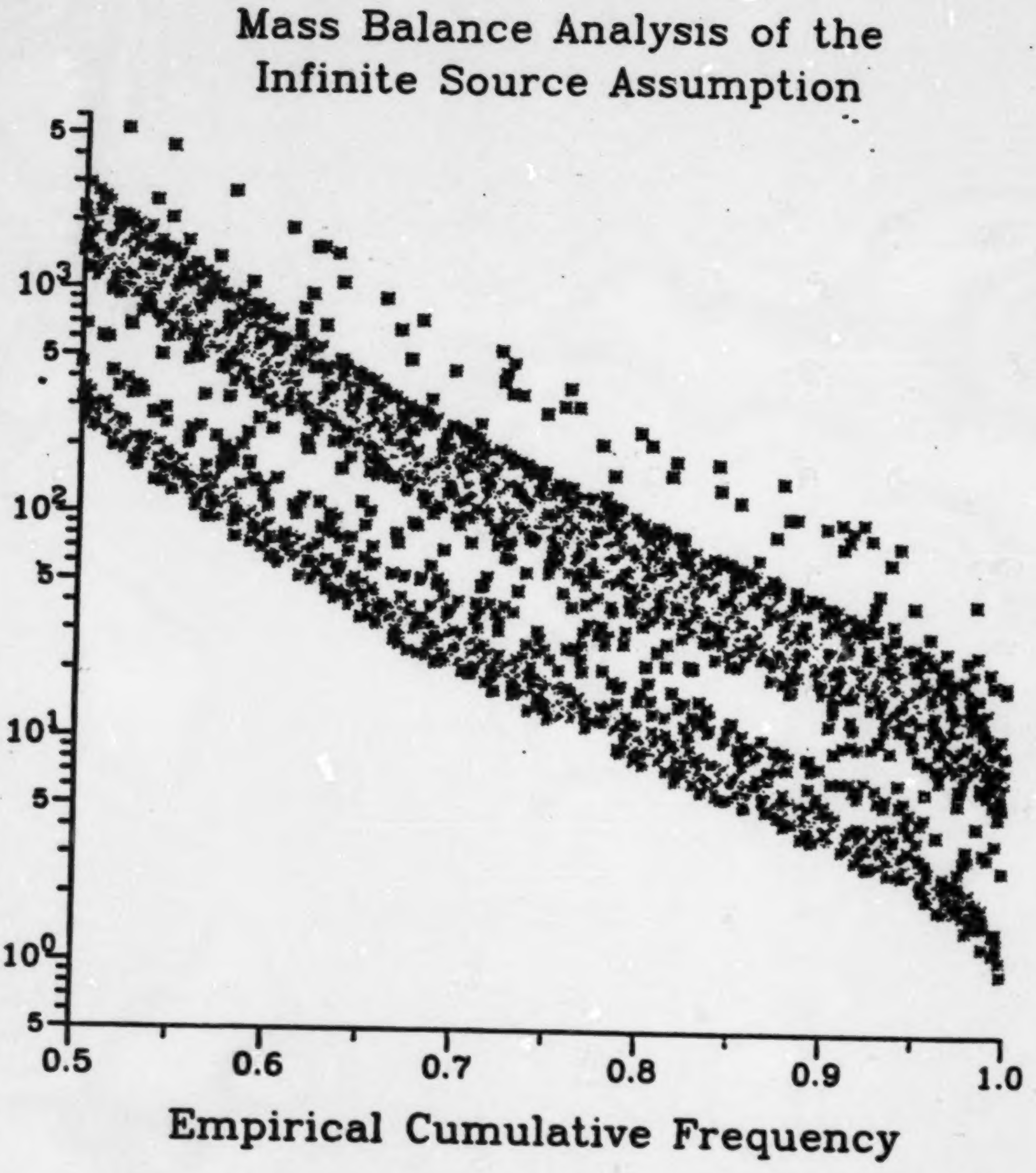

Figure 8. Minimum Constituent Concentration in Waste Required to Produce Exposure Duration of 70 years.

DRAFT

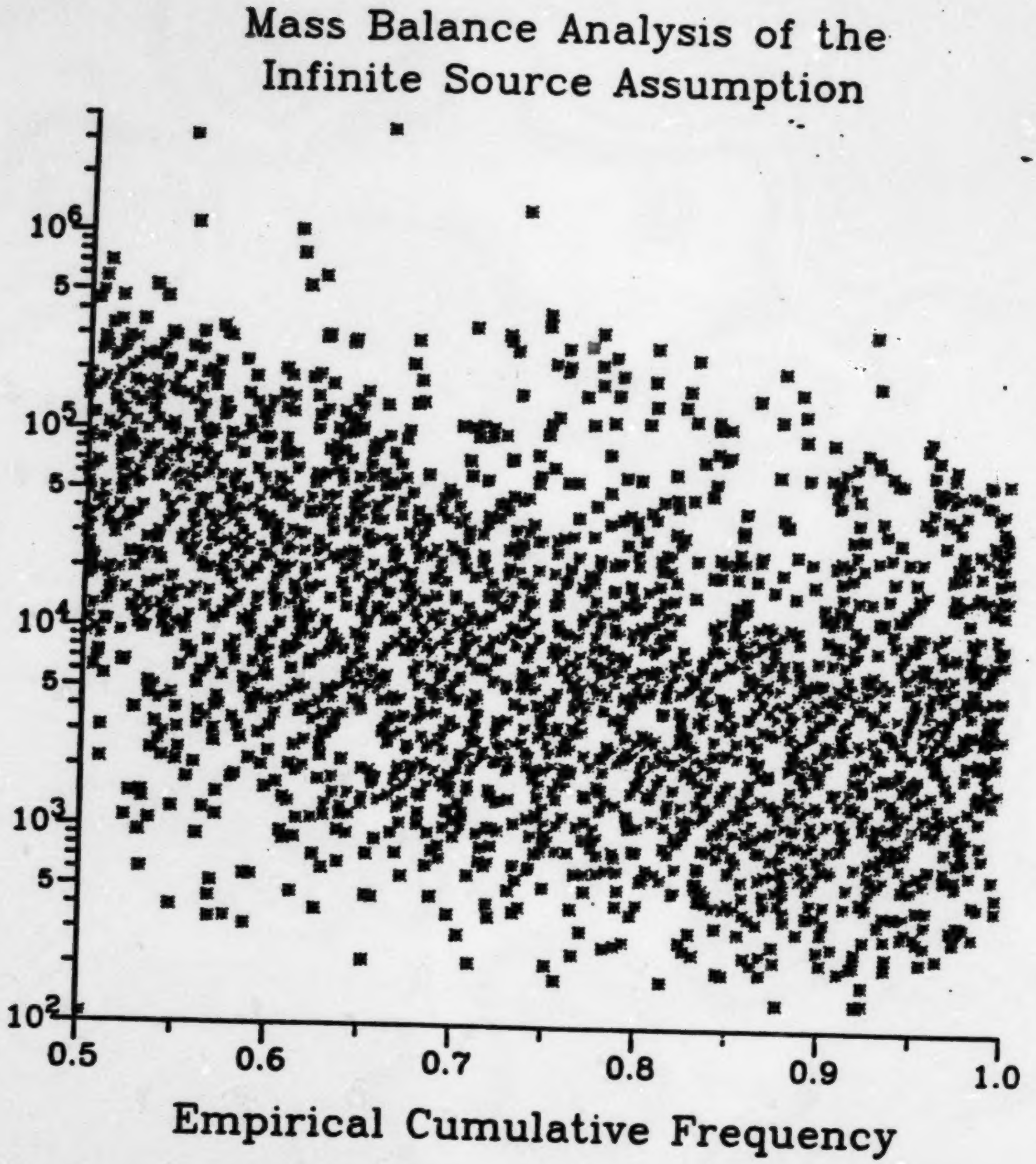

Figure 9. Minimum Mass of Constituent Required in Facility to Produce Exposure Duration of 70 years

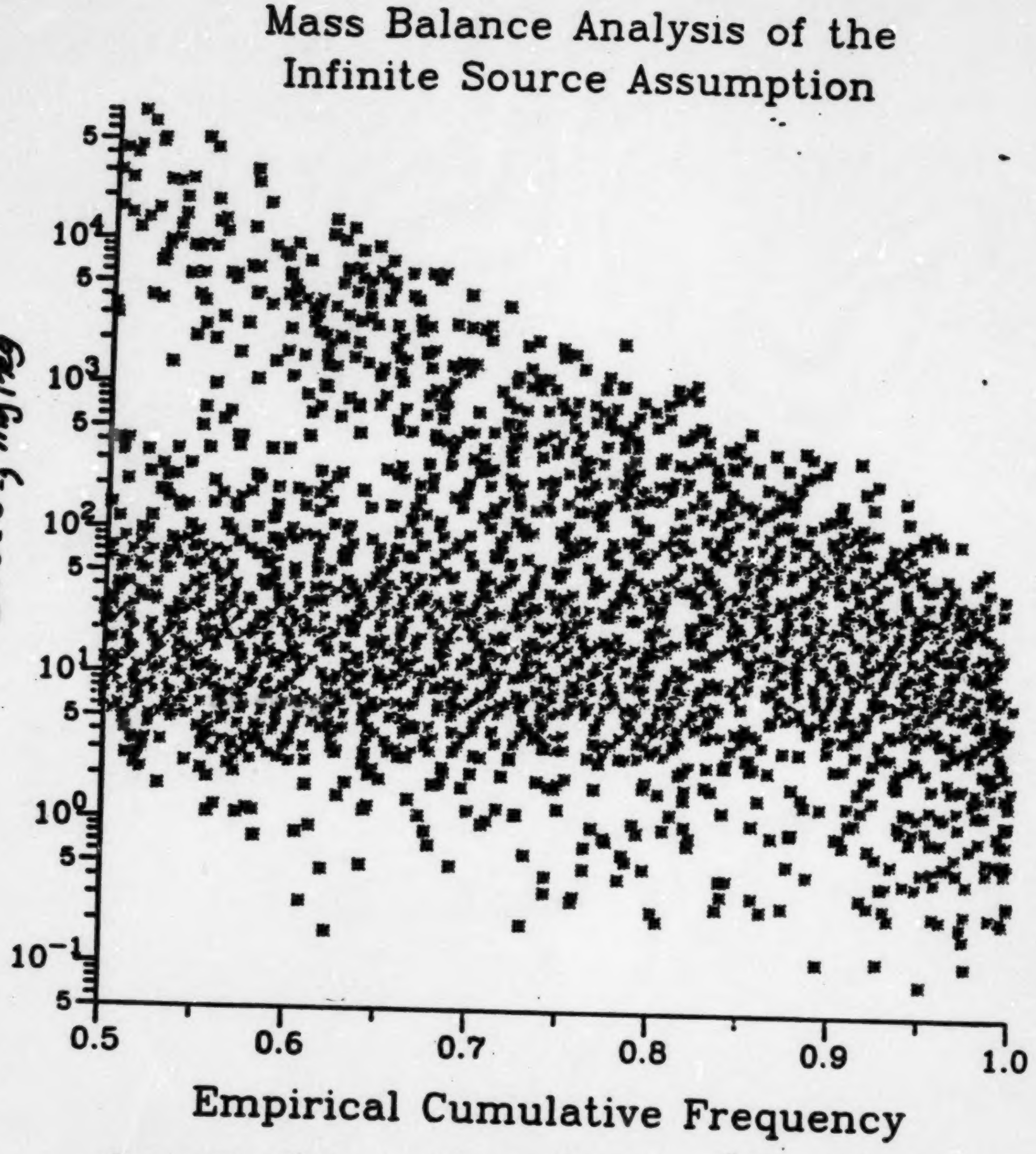

Figure 10. Minimum Concentration of Constituent in Waste to Produce Fully Developed Groundwater Plume

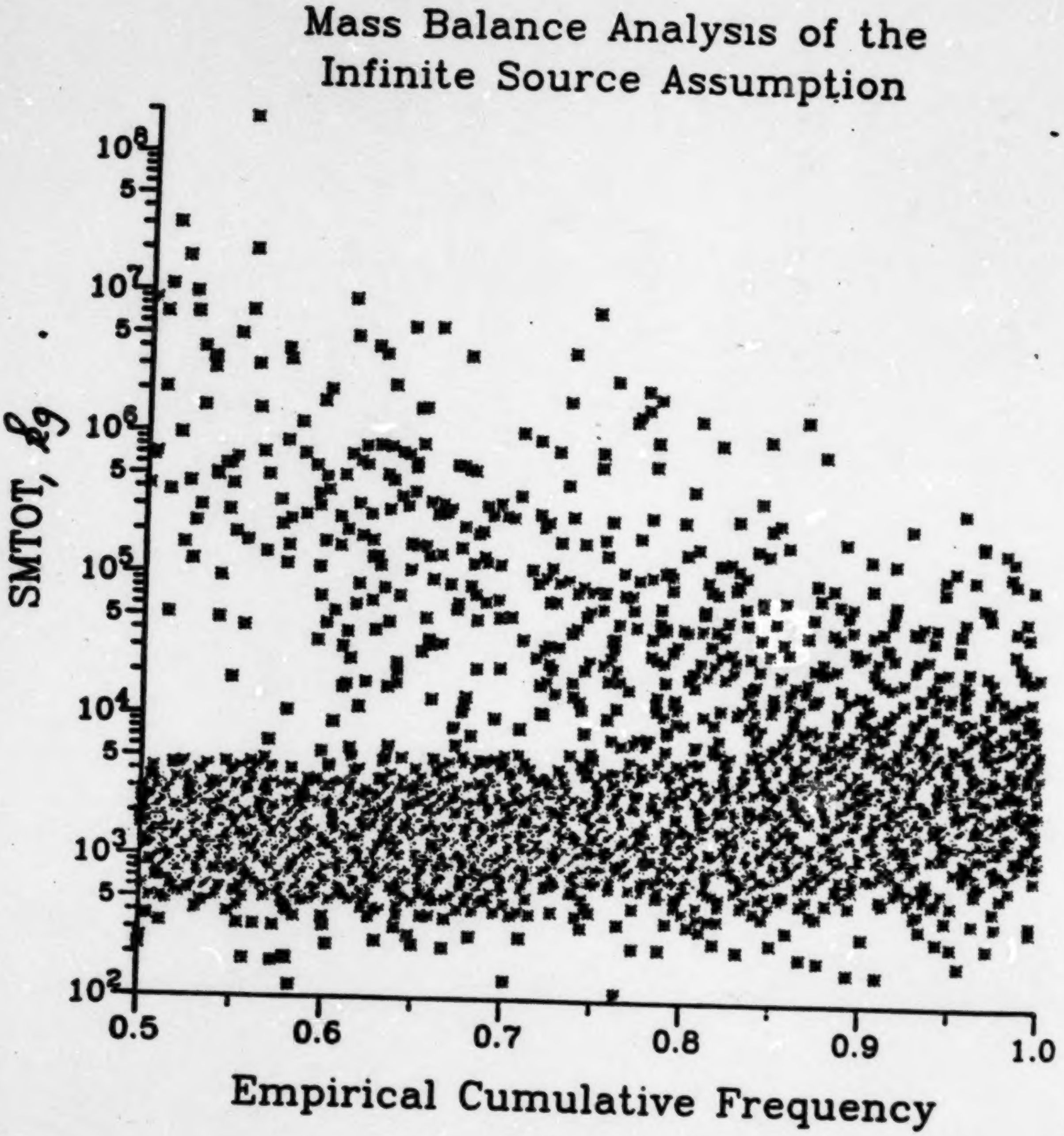

Figure 11 Minimum Mass of Constituent Required in Facility to Produce Fully Developed Groundwater Plume.

App G

APPENDIX G

FORTRAN LISTING

GROUND WATER SCREENING PROCEDURE

```
C-----------------------------------------------------------------------
C     This version was modified to run on an IBM system by DPRA, Inc.
C-----------------------------------------------------------------------
C
C
C       MCARLO.FTN          DB2:[205,202]                     MCARLO.FTN
C
C     This version was created 10/15/85 from the QSTAR9 version
C     created 10/12/85 except now print CD, LWCMIN
C
      IMPLICIT REAL*8   (A-H,O-Z)
      REAL*8            LWCMIN,LWCTOT
      INTEGER*2 NPROB
      INTEGER*2 NMAXCK(9),IUNIT1,IUNIT2,IUNIT3,IPSPEC,
     x                  NSIGMA,NLAMDA,NX,NVN,IPCAL,IRCHGE,NMAX,CHOICE,
     x                  IX,IY,ILEACH
      CHARACTER MENU,ANS,TITLE*60,TERM,VTANSI(4),LEACH(2)
      DOUBLE PRECISION SEED1,SEED2,SEED3,SEED4
      COMMON/SEEDS/ SEED1,SEED2,SEED3,SEED4
      COMMON/CLEARS/ TERM
      COMMON/INTEGS/ IPSPEC,NSIGMA,NLAMDA,NX,NVN,IPCAL,IRCHGE,NMAX
      COMMON/REALS/ SIGMA(1),RHOB,THETA,TCONV,DKA,DKB,DKN,PH,DKOC,FOC,
     x               ADI,XX(1),ALFAL,ALFAT,VN(1),RCHGE(1),DKS,
     x               HSOURC,BAQFR,AN,ALFAZ
      COMMON/IO/ IUNIT1,IUNIT2,IUNIT3
        COMMON/BLOCKA/CD(1,1,1),XD(1),GLAMD(1),SD(1),
     1                 ZZ(1),GLAM(1)
        COMMON/BLOCKP/CPF(1,1,1),DLFAC(1,1,1)
      COMMON/NEWOUT/SMMIN,SMTOT,LWCMIN,LWCTOT,DF,RHOW,Q
C       Declare all data statements.
C
C       DATA  VTANSI / 2*' ',27,'<' /
        DATA  NPROB,TITLE / 1000,' ' /
        DATA  NMAXCK / 4, 5, 6, 10, 15, 20, 60, 104, 256 /
        DATA  TWOPI / 6.2831853071796D0 /
        DATA  ILEACH,LEACH / 1,'C','D' /
        DATA  DKA0, DKB0, DKN0 / 0.0, 0.0, 0.0 /
CC    DATA  DLON,DAZIM / 40.0, 330.0 /
C
```

```
C 45  WRITE (6,50)
C 50  FORMAT (' Enter (1) for VT100 or (2) for VT52 terminal > ')
C     READ (5,100) TERM
C     IF ( TERM .NE. '1' .AND. TERM .NE. '2' ) GO TO 45
C     IF (TERM .EQ. '1') WRITE (6,100) VTANSI
 100  FORMAT (4A1)
C
C       Display the Menu.
C
 200  CALL CLSCR
      WRITE (6,305) ADI,DKA0,DKB0,DKN0,DKOC,NMAX,NPROB,
     x                    TCONV,TR,XX(1),LEACH(ILEACH),DF,RHOM
 305  FORMAT (3(/),
     x          5X,'A - ADI     (Value =',G11.5,')',/,
     x          5X,'B - DKA0    (Value =',G11.5,')',/,
     x          5X,'C - DKB0    (Value =',G11.5,')',/,
     x          5X,'D - DKN0    (Value =',G11.5,')',/,
     x          5X,'E - DKOC    (Value =',G11.5,')',/,
     x          5X,'F - NMAX    (Value =',I11,')  # of Gauss points',/,
     x          5X,'G - NPROB   (Value =',I11,')  # of plot points',/,
     x          5X,'H - TCONV   (Value =',G11.5,')',
     x              '  Units are per year for rate constants',/,
     x          5X,'I - T(ref)  (Value =',G11.5,')',/,
     x          5X,'J - XX      (Value =',G11.5,')',/,
     x          5X,'K -         ( Subtitle ',A1,' Used  )',
     x              '  Leaching Rate Distribution',/,
     x          5X,'L - DF      (Value =',G11.5,')',/,
     x          5X,'M - RHOM    (Value =',G11.5,')',/,
     x          5X,'S - Start the Calculations',/,
     x          5X,'X - Exit Program',//,
     x          5X,'Select a letter -> ')
      READ (5,315,END=2300,ERR=200) MENU
 315  FORMAT (A1)
 355  FORMAT (F12.0)
 365  FORMAT (I6)
C
      CHOICE = INDEX('ABCDEFGHIJKLMSXabcdefghijklmsx',MENU)
      IF (CHOICE .EQ. 0) GO TO 200
      IF (CHOICE .GT. 15) CHOICE = CHOICE - 15
C
 300  CALL CLSCR
      GO TO (400,440,480,520,560,600,640,680,720,760,
     X          800,810,820,840,2300),
     X          CHOICE
      GO TO 200
C
 400  WRITE(6,405)
 405  FORMAT(' Enter ADI > ')
      READ (5,355,ERR=400,END=2300) ADI
      IF (ADI .LE. 0.000) GO TO 300
      GO TO 200
C
 440  WRITE(6,445)
 445  FORMAT(' Enter DKA0 > ')
      READ (5,355,ERR=440,END=2300) DKA0
      IF (DKA0 .LT. 0.000) GO TO 300
      GO TO 200
C
 480  WRITE(6,485)
 485  FORMAT(' Enter DKB0 > ')
      READ (5,355,ERR=480,END=2300) DKB0
```

3

```
      IF (DKB0 .LT. 0.0D0) GO TO 300
      GO TO 200
C
 520  WRITE(6,525)
 525  FORMAT(' Enter DKN0 > ')
      READ (5,355,ERR=520,END=2300) DKN0
      IF (DKN0 .LT. 0.0D0) GO TO 300
      GO TO 200
C
 560  WRITE(6,565)
 565  FORMAT(' Enter DKOC > ')
      READ (5,355,ERR=560,END=2300) DKOC
      IF (DKOC .LT. 0.0D0) GO TO 300
      GO TO 200
C
 600  WRITE(6,605)
 605  FORMAT(////,' Enter NMAX (number of Gauss points) > ')
      READ (5,365,ERR=600,END=2300) NMAX
      DO 610 I = 1,9
 610  IF ( NMAX .EQ. NMAXCK(I) ) GO TO 200
      WRITE (6,615) NMAX
 615  FORMAT(//,' You entered ',I9,'. Please reenter',/,
     *              ' 4, 5, 6, 10, 15, 20, 60, 104, 256',///,
     *              ' Hit Carriage Return to Continue')
      READ (5,315,ERR=300,END=2300) MENU
      GO TO 300
C
 640  WRITE(6,645)
 645  FORMAT(////,' Enter NPROB (number of Plot points) > ')
      READ (5,365,ERR=640,END=2300) NPROB
      IF (NPROB .LT. 500) GO TO 300
      GO TO 200
C
 680  WRITE(6,685)
 685  FORMAT(' Enter TCONV > ')
      READ (5,355,ERR=680,END=2300) TCONV
      IF (TCONV .LE. 0.0D0) GO TO 300
      GO TO 200
C
 720  WRITE(6,725)
 725  FORMAT(' Enter T<ref> ')
      READ (5,355,ERR=720,END=2300) TR
      IF (TR .LE. 0.0D0 .OR. TR .GT. 50.0D0) GO TO 300
      GO TO 200
C
 760  WRITE(6,765)
 765  FORMAT(' Enter XX > ')
      READ (5,355,ERR=760,END=2300) XX(1)
      IF (XX(1) .LE. 0.0D0) GO TO 300
      GO TO 200
C
 800  ILEACH = 3 - ILEACH
      GO TO 200
C
 810  WRITE(6,811)
 811  FORMAT(' Enter DF > ')
      READ (5,355,ERR=810,END=2300) DF
      IF (DF .LE. 0.0D0) GO TO 300
      GO TO 200
C
 820  WRITE(6,821)
```

```
  821  FORMAT(' Enter RHOM > ')
       READ (5,355,ERR=820,END=2300) RHOM
       IF (RHOM .LE. 0.0D0) GO TO 300
       GO TO 200
C
C        Perform calculations
C
  840      CALL CLSCR
C          OPEN(UNIT=IUNIT1,FILE='MCARLO.DAT',STATUS='NEW',
C    *                         CARRIAGECONTROL='LIST')
C          OPEN(UNIT=IUNIT2,FILE='MCARLO.INF',STATUS='NEW')
C
C        Write information
C
      WRITE (2,2150) ADI,DKA0,DKB0,DKH0,DKOC,NMAX,NPROB,
     *                         TCONV,TR,XX(I),LEACH(ILEACH),DF,RHOM
 2150  FORMAT (/,2X,'A - ADI      (Value =',G12.6,')',/,
     *           2X,'B - DKA0     (Value =',G12.6,')',/,
     *           2X,'C - DKB0     (Value =',G12.6,')',/,
     *           2X,'D - DKH0     (Value =',G12.6,')',/,
     *           2X,'E - DKOC     (Value =',G12.6,')',/,
     *           2X,'F - NMAX     (Value =',I12,')  # of Gauss points',/,
     *           2X,'G - NPROB    (Value =',I12,')  # of plot points',/,
     *           2X,'H - TCONV    (Value =',G12.6,')',
     *                  '  Units are per year for rate constants',/,
     *           2X,'I - T(ref)  (Value =',G12.6,')',/,
     *           2X,'J - XX       (Value =',G12.6,')',/,
     *           2X,'K -          (  Subtitle ',A1,' Used  )',
     *                  '  Leaching Rate Distribution',/,
     *           2X,'L - DF       (Value =',G11.5,')',/,
     *           2X,'M - RHOM     (Value =',G11.5,')',/)
          CALL CLSCR
        WRITE(6,2160)
 2160   FORMAT (10(/),15X,'Calculations are being Performed',//)
        SEED1 = 123457.0D0
        SEED2 = 123457.0D0
        SEED3 = 123457.0D0
        SEED4 = 123457.0D0
        IX = 1235
        IY = 8765
        DO 2200 I = 1, NPROB
C
C       New code
C
 2170   DDLMIN = DLOG10(4.0D-4)
        DDLMAX = DLOG10(1.0D-1)
        CALL RANDUM(DDLMIN,DDLMAX,DD)
        DD = 10.0D0**DD
        THETA = 0.261 - 0.0388 * ( DLOG(DD) )
        RHOB = 2.65 * ( 1.0D0 - THETA )
        DKS = 478.0 * (THETA**3.0D0 * DD**2.0D0
     *                   / (1.D0 - THETA)**2.0D0)
CCCCC   CALL RANDUM(1.0D-5,0.1D0,SS)
 2180   CALL EXRAND(0.0309,1,SS)
        IF ( SS .LT. 1.0D-5 .OR. SS .GT. 1.0D-1 ) GO TO 2180
        VW(I) = (3.1536D8 * DKS * SS) / THETA
        IF ( VW(I) .GT. 9250.0D0 ) GO TO 2170
C
C      Code added 06/08/88
C
        TRK = TR + 273.0D0
 2190       CALL RANNOR ( 14.4D0, 27.95D0, T )
          IF ( T .LT. 0.0D0 .OR. T .GT. 30.0D0 ) GO TO 2190
          T = T + 273.0D0
 C
          DKA = DKA0 * ( DEXP( 1.0D4 * ( 1.0D0 / TRK - 1.0D0 / T )))
          DKN = DKN0 * ( DEXP( 1.0D4 * ( 1.0D0 / TRK - 1.0D0 / T )))
          DKB = DKB0 * ( DEXP( 1.0D4 * ( 1.0D0 / TRK - 1.0D0 / T )))
 C
 2195     CALL RANNOR ( 6.62D0, 1.65D0, PH )
          IF ( PH .LT. 0.3D0 .OR. PH .GT. 14.0D0 ) GO TO 2195
 C
 C CODE ADDED 8/26/88 BY JEROME COLEMAN
 C QC IS THE Q VALUE FOR SUBTITLE C
 C QD IS THE Q VALUE FOR SUBTITLE D
 C
 C
        IF(ILEACH.EQ.1)THEN
 C
 C        Call Rudy's subroutines
 C
          CALL TBLC(QC,QD,IX,IY)
           IF ( QC .LE. 0.01D0 ) QC = 0.00001D0
           QC = QC * 0.0254D0
           IF ( QD .LE. 0.01D0 ) QD = 0.00001D0
           QD = QD * 0.0254D0
          Q=QC
        ELSE
 C
 C        Call Rudy's subroutines
 C
          CALL TBLD(QC,QD,IX,IY)
           IF ( QC .LE. 0.01D0 ) QC = 0.00001D0
           QC = QC * 0.0254D0
           IF ( QD .LE. 0.01D0 ) QD = 0.00001D0
           QD = QD * 0.0254D0
          Q=QD
        ENDIF
 C
           CALL EXRAND(78.6D0,1,BAQFR)
           BAQFR = BAQFR + 3.0D0
 C      WRITE(2,111)' BAQFR= ',BAQFR
 C111   FORMAT(1X,A10,F15.7)
 C
 C        B2 added coded on 6/10/88.
 C
           CALL RANDUM (2.0D,10.0D,HINIT)
           IF ( HINIT / BAQFR .GT. 0.5D0 ) THEN
          HSOURC = 0.5D0 * BAQFR
           ELSE
          HSOURC = HINIT
           END IF
 C
 CC
 CC ADDITION 08/19/88 BY JEROME COLEMAN
 CC
           RCHSE(1)=QD/HSOURC
 C
 C
 C
 2199      CALL RANDUM(0.0D0,1.0D0,UU)
           IF ( UU .LE. 0.9167D0 ) THEN
```

6

```
          UU = UU / 0.9107100
                  AM = -25752.0D0 * DLOG ( 1.0D0 - UU )
                  IF ( AM .LT. 0.0D0 .OR. AM .GT. 1.8D5 ) GO TO 2199
           ELSE
          CALL RANDUM (0.0D0,1.0D0,UU)
          AM = 1.5D5 + 7.79D5 * UU
           END IF
C
C
C
C
C
          SIGMA(1) = ( Q * AM ) /
     *                 ( THETA * VW(1) * DSQRT(TWOPI) * HSOURC )
          IF ( Q .LE. 0.0234D0 ) SIGMA(1) = 0.001D0
CC
CC CODE ADDED 08/28/88 BY JEROME COLEMAN
CC
CC      SAM = DSQRT(AM)
CC      IF ( SIGMA(1) .GT. SAM ) THEN
CC        SIGMA(1) =  SAM
CC        VW(1) = (Q*AM)/(THETA*SIGMA(1)*DSQRT(TWOPI)*HSOURC)
CC        SS = (VW(1)*THETA)/(3.15D5*DKS)
CC        IF(SS .LE. 1.0D-1)GOTO 2105
CC        IF(SS .GT. 1.0D-1)GOTO 2170
CC      ENDIF
CC
CC
CC
CC
C         Code added 06/28/88
C
2105   ALFAL = 0.1D0 * XX(1)
       ALFAT = ALFAL / 3.0D0
C      RCHGE(1) = 0.00
       CALL LNDREH (-5.200,2.060,FOC)
          ALZLO = 0.025D0 * ALFAL
          ALZHI = 0.1D0 * ALFAL
          CALL RANDUM ( ALZLO, ALZHI, ALFAZ )
C
          CALL CAD
C
       IF (I .EQ. 1 .OR. I .EQ. NPROB)
     *      WRITE (2,2205) I,ALFAL,ALFAT,ALFAZ,AM,BAGFR,CD(1,1,1),
     *                     DKA0,DKB0,DKH0,FOC,HIMIT,HSOURC,
     *                     PH,RHOB,SIGMA(1),T,THETA,VW(1),XX(1),
     *                     DF,RHOW
2200      CONTINUE
2205   FORMAT (/,T3,'Pass = ',I5,/,
     *             T5 ,' ALFAL = ',G12.6,T30,' ALFAT = ',G12.6,
     *             T55,' ALFAZ = ',G12.6,/,
     *             T5 ,'    AM = ',G12.6,T30,' BAGFR = ',G12.6,
     *             T55,'    CD = ',G12.6,/,
     *             T5 ,'  DKA0 = ',G12.6,T30,'  DKB0 = ',G12.6,
     *             T55,'  DKH0 = ',G12.6,/,
     *             T5 ,'   FOC = ',G12.6,T30,' HIMIT = ',G12.6,
     *             T55,'HSOURC = ',G12.6,/,
     *             T5 ,'    PH = ',G12.6,T30,'  RHOB = ',G12.6,
     *             T55,' SIGMA = ',G12.6,/,
     *             T5 ,'     T = ',G12.6,T30,' THETA = ',G12.6,
     *             T55,'    VW = ',G12.6,/,
     x              T5 ,'    XX = ',G12.6,/,
     x              T5 ,'    DF = ',G12.6,T30,'  RMON = ',G12.6,/)
C       CLOSE(UNIT=IUNIT1)
C       CLOSE(UNIT=IUNIT2)
C
 2220   CALL CLSCR
        WRITE(6,2225)
 2225   FORMAT(//////////,
     x    ' Do you want to make another run (Y/N) > ')
        READ(5,315,END=2300,ERR=2220)MENU
       IF ( INDEX ( 'YNyn',MENU ) .EQ. 0 ) THEN
              CALL CLSCR
              WRITE (6,2235) MENU
 2235     FORMAT (' You entered <',A1,'>. Please reenter')
              GO TO 2220
       ENDIF
        IF ( MENU .EQ. 'Y' .OR. MENU .EQ. 'y' ) GO TO 200
 2300 CONTINUE
      STOP
      END

        BLOCK DATA
        IMPLICIT REAL*8 (A-H,O-Z)
        REAL*8 LMCMIN,LMCTOT
        INTEGER*2       IUNIT1,IUNIT2,IUNIT5,IPSPEC,
     x                  NSIGMA,NLAMDA,NX,NVN,IPCAL,IRCHGE,NMAX,CHOICE
        CHARACTER       TERM
        COMMON/CLEARS/ TERM
        COMMON/INTERS/ IPSPEC,NSIGMA,NLAMDA,NX,NVN,IPCAL,IRCHGE,NMAX
        COMMON/REALS/ SIGMA(1),RNOD,THETA,TCONV,DKA,DKB,DKM,PH,DKOC,FOC,
     x                ADI,XX(1),ALFAL,ALFAT,VN(1),RCHGE(1),DKS,
     x                HSOURC,BAQFR,AN,ALFAZ
        COMMON/IO/ IUNIT1,IUNIT2,IUNIT5
        COMMON/BLOCKA/CD(1,1,1),XD(1),GLAMD(1),SD(1),ZZ(1),GLAM(1)
        COMMON/BLOCKP/CPF(1,1,1),DLFAC(1,1,1)
        COMMON/NEWOUT/SMMIN,SMTOT,LMCMIN,LMCTOT,DF,RMON,Q
C              Declare all data statements.
        DATA  IUNIT1,IUNIT2,IUNIT5,TERM / 1, 2, 5, '1' /
        DATA  IPSPEC,NSIGMA,NLAMDA,NX,NVN,IPCAL,IRCHGE /
     x           1,    1,    1, 1,  1,    1,     1 /
        DATA  NMAX,SIGMA,RNOD,THETA,TCONV /
     x         15, 15.0, 1.6, 0.35,  1.0 /
        DATA   PH,  DKOC,  FOC, ADI,  XX,  ALFAL,ALFAT, VN, RCHGE /
     x        7.0, 100.0, 0.01, 1.0, 150.0, 10.0,  1.0, 0.0, 0.0 /
        DATA  DF,RMON / 5.0, 1.0 /
        END

      SUBROUTINE CLSCR
C     CHARACTER CLR1(10),CLR2(10),TERM
C       INTEGER*2 IUNIT1,IUNIT2,IUNIT5
C     COMMON/IO/ IUNIT1,IUNIT2,IUNIT5
C     COMMON/CLEARS/ TERM
C       DATA CLR1 / ' ',27,'[','1',';','1','f',27,'[','J' /
C       DATA CLR2 /6*' ',27,'H',27,'J' /
C     IF ( TERM .EQ. '1' ) WRITE(6,10)CLR1
C     IF ( TERM .EQ. '2' ) WRITE(6,10)CLR2
C 10  FORMAT (10A1)
      DO 10 I=1,24
        WRITE(6,11)
 11     FORMAT(' ')
 10     CONTINUE
```

9

```
      RETURN
      END
C=====================================================================
C  TBLC.FTN - 5/31/85
C
C  ROUTINE TO PRODUCE A RANDOM NUMBER ON THE BASIS OF A
C  TABLE-SPECIFIED EMPIRICAL DISTRIBUTION
C
C=====================================================================
C
      SUBROUTINE TBLC (RESC,RESD,IX,IY)
C
      IMPLICIT REAL*8   (A-H,O-Z)
      INTEGER*2 IX,IY
      DIMENSION TABLEC(13,2)
      DIMENSION TABLED(15,2)
C
      DATA TABLEC/.01,.3,.4,.5,2.5,2.9,3.3,3.6,3.7,6.9,7.0,8.0,11.9,
     * .29,.38,.49,.58,.63,.66,.73,.76,.81,.92,.95,.98,1.0/
C
C
      DATA TABLED/.1,.2,.3,.6,.8,1.2,1.5,2.4,4.0,5.0,6.0,7.2,12.1,12.2,
     * 35.9, .03,.06,.08,.26,.29,.40,.53,.58,.61,.66,.70,.81,.95,.98,
     * 1.0/
C
      CALL RANDU(IX,IY,YFL)
C
C  CHECK VS TABLEC
      IF(YFL.GT.TABLEC(1,2))GO TO 100
C
      RESC=TABLEC(1,1)
      GO TO 102
C
C  DO TABLE LOOKUP, INTERPOLATION
C
100   DO 101 I=2,13
      IF(YFL.GT.TABLEC(I,2))GO TO 101
      SLOPE = (TABLEC(I,2)-TABLEC(I-1,2))/(TABLEC(I,1)-TABLEC(I-1,1))
      RESC = TABLEC(I-1,1) + (YFL-TABLEC(I-1,2))/SLOPE
      GO TO 102
101   CONTINUE
C
      RESC = TABLEC(13,1)
102   CONTINUE
C
C  now for D
C
C  CHECK VS TABLE
C
      IF(YFL.GT.TABLED(1,2))GO TO 200
C
      RESD=TABLED(1,1)
      GO TO 299
C
C  DO TABLE LOOKUP, INTERPOLATION
C
200   DO 201 I=2,15
      IF(YFL.GT.TABLED(I,2))GO TO 201
      SLOPE = (TABLED(I,2)-TABLED(I-1,2))/(TABLED(I,1)-TABLED(I-1,1))
      RESD = TABLED(I-1,1) + (YFL-TABLED(I-1,2))/SLOPE
      GO TO 299
```

```
201   CONTINUE
C
      RESD = TABLED(15,1)
C
299   RETURN
      END
C==================================================================
C  TBLD.FTN - 8/31/85
C
C  ROUTINE TO PRODUCE A RANDOM NUMBER ON THE BASIS OF A
C  TABLE-SPECIFIED EMPIRICAL DISTRIBUTION
C
C==================================================================
C
      SUBROUTINE TBLD (RESC,RESD,IX,IY)
C
      IMPLICIT REAL*8   (A-H,O-Z)
      INTEGER*2 IX,IY
      DIMENSION TABLEC(13,2)
      DIMENSION TABLED(15,2)
C
      DATA TABLEC/.01,.3,.4,.5,2.5,2.9,3.3,3.6,3.7,6.9,7.8,8.0,11.9,
     * .29,.38,.49,.58,.63,.66,.73,.76,.81,.92,.95,.98,1.0/
C
C
      DATA TABLED/.1,.2,.3,.6,.8,1.2,1.5,2.4,4.8,5.8,6.8,7.2,12.1,12.2,
     * 35.9, .03,.06,.08,.26,.29,.40,.53,.58,.61,.66,.78,.81,.95,.98,
     * 1.0/
C
C  GENERATE A UNIFORM (0,1)
C
      CALL RANDU(IX,IY,YFL)
C
C  now for D
C
C  CHECK VS TABLE
C
      IF(YFL.GT.TABLED(1,2))GO TO 200
C
      RESD=TABLED(1,1)
      GO TO 299
C
C  DO TABLE LOOKUP, INTERPOLATION
C
200   DO 201 I=2,15
      IF(YFL.GT.TABLED(I,2))GO TO 201
      SLOPE = (TABLED(I,2)-TABLED(I-1,2))/(TABLED(I,1)-TABLED(I-1,1))
      RESD = TABLED(I-1,1) + (YFL-TABLED(I-1,2))/SLOPE
      GO TO 299
201   CONTINUE
C
      RESD = TABLED(15,1)
C
299   CONTINUE
C
C  now for C
C
C  CHECK VS TABLEC
      IF(YFL.GT.TABLEC(1,2))GO TO 100
C
      RESC=TABLEC(1,1)
```

10

```
      GO TO 102
C
C  DO TABLE LOOKUP, INTERPOLATION
C
100   DO 101 I=2,13
      IF(YFL.GT.TABLEC(I,2))GO TO 101
      SLOPE = (TABLEC(I,2)-TABLEC(I-1,2))/(TABLEC(I,1)-TABLEC(I-1,1))
      RESC = TABLEC(I-1,1) + (YFL-TABLEC(I-1,2))/SLOPE
      GO TO 102
101   CONTINUE
C
      RESC = TABLEC(13,1)
102   RETURN
      END
C=====================================================================
C  TBLINTRP.FTN - 5/31/85
C
C  ROUTINE TO PRODUCE A RANDOM NUMBER ON THE BASIS OF A
C  TABLE-SPECIFIED EMPIRICAL DISTRIBUTION
C
C=====================================================================
C
      SUBROUTINE TBLINT (RESULT,IX,IY)
C
      IMPLICIT REAL*8   (A-H,O-Z)
      INTEGER*2 IX,IY
      DIMENSION TABLE(13,2)
C
      DATA TABLE/.01,.3,.4,.5,2.5,2.9,3.3,3.6,3.7,6.9,7.0,8.0,11.9,
     * .29,.38,.49,.58,.63,.66,.73,.76,.81,.92,.95,.98,1.0/
C
C     DO 200 I=1,13
C
C  GENERATE A UNIFORM (0,1)
C
      CALL RANDU(IX,IY,YFL)
C
C  CHECK VS TABLE
      IF(YFL.GT.TABLE(1,2))GO TO 100
C
      RESULT=TABLE(1,1)
      GO TO 99
C
C  DO TABLE LOOKUP, INTERPOLATION
C
100   DO 1 I=2,13
      IF(YFL.GT.TABLE(I,2))GO TO 1
      SLOPE = (TABLE(I,2)-TABLE(I-1,2))/(TABLE(I,1)-TABLE(I-1,1))
      RESULT = TABLE(I-1,1) + (YFL-TABLE(I-1,2))/SLOPE
      GO TO 99
    1 CONTINUE
C
      RESULT = TABLE(13,1)
C
   99 RETURN
      END
C=====================================================================
C  TBLINTRPD.FTN - 07/10/85
C
      SUBROUTINE TBLIN2 (RESULT,IX,IY)
C
```

```
      IMPLICIT REAL*8   (A-H,O-Z)
      INTEGER*2 IX,IY
      DIMENSION TABLE(15,2)
C
      DATA TABLE/.1,.2,.3,.6,.8,1.2,1.5,2.4,4.0,5.0,6.0,7.2,12.1,12.2,
     * 35.9, .03,.06,.08,.26,.29,.40,.53,.58,.61,.66,.70,.81,.95,.98,
     * 1.0/
C
C  GENERATE A UNIFORM (0,1)
C
      CALL RANDU(IX,IY,YFL)
C
C  CHECK VS TABLE
      IF(YFL.GT.TABLE(1,2))GO TO 100
C
      RESULT=TABLE(1,1)
      GO TO 99
C
C  DO TABLE LOOKUP, INTERPOLATION
C
100   DO 1 I=2,15
      IF(YFL.GT.TABLE(I,2))GO TO 1
      SLOPE = (TABLE(I,2)-TABLE(I-1,2))/(TABLE(I,1)-TABLE(I-1,1))
      RESULT = TABLE(I-1,1) + (YFL-TABLE(I-1,2))/SLOPE
      GO TO 99
    1 CONTINUE
C
      RESULT = TABLE(15,1)
C
   99 RETURN
      END
C=====================================================================
      SUBROUTINE RANDU(IX,IY,YFL)

      IMPLICIT REAL*8   (A-H,O-Z)
      INTEGER*2 IX,IY
      DATA IA,IB,IC/259,32767,1/

      IY=IX*IA
      IF(IY)5,6,6
    5 IY=(IY+IB)+IC
    6 YFL=IY
      YFL=YFL*.30518509E-4
      IX=IY
      RETURN
      END

C               LNDGEN.FTN
C
      SUBROUTINE LNDGEN (MEAN,VARI,VALUE)
      IMPLICIT REAL*8   (A-H,O-Z)
      DOUBLE PRECISION   VALUE,SEED1,SEED2,SEED3,SEED4
      COMMON/SEEDS/ SEED1,SEED2,SEED3,SEED4
      REAL       MEAN, VARI, VALUES(2)
   10 CALL GGNLG (SEED1, 1, MEAN, VARI, VALUES)
      VALUE = VALUES(1)
      IF (VALUE .LT. 1.00D-3 .OR. VALUE .GT. 1.00D-2) GO TO 10
      RETURN
      END
C               RANNOR.FTN
```

```
C
      SUBROUTINE RANNOR(MEAN,VARI,VALUEO)
      IMPLICIT REAL*8   (A-H,O-Z)
      DOUBLE PRECISION  VALUEO,SEED1,SEED2,SEED3,SEED4
      COMMON/SEEDS/ SEED1,SEED2,SEED3,SEED4
      REAL      MEAN, VARI, VALUE(1)
      CALL GGNML ( SEED2, 1, VALUE(1) )
      VALUEO = MEAN + SQRT(VARI) * VALUE(1)
      RETURN
      END
C               RANDUM.FTN
C
      SUBROUTINE RANDUM(LOWER,UPPER,VALUEO)
      IMPLICIT REAL*8   (A-H,O-Z)
      DOUBLE PRECISION  VALUEO,SEED1,SEED2,SEED3,SEED4
      COMMON/SEEDS/ SEED1,SEED2,SEED3,SEED4
      REAL      LOWER, UPPER, VALUE
      VALUE = GGUBFS(SEED3)
      VALUEO = LOWER + VALUE * ( UPPER - LOWER)
      RETURN
      END
C               EXRAND.FTN
C
      SUBROUTINE EXRAND(XM,NR,VALUEO)
      IMPLICIT REAL*8   (A-H,O-Z)
      DOUBLE PRECISION  VALUEO,SEED1,SEED2,SEED3,SEED4
      COMMON/SEEDS/ SEED1,SEED2,SEED3,SEED4
      REAL      XM, VALUE
      CALL GGEXN ( SEED4, XM, NR, VALUE )
      VALUEO = VALUE
      RETURN
      END

      SUBROUTINE CAD
C.....   EPASMOD-1:  COMPUTES SUDICKY'S STEADY-STATE ANALYTICAL SOLUTION
C                    DISTRIBUTION OF CONCENTRATION AT X = 0.  THE CODE
C                    DETERMINES ONLY CONCENTRATION VALUES ALONG THE X-AXIS
C INSERT SYSCOM>ERRD.F
C INSERT SYSCOM>KEYS.F
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 IUNIT1,IUNIT2,IUNIT3,
     *          IPSPEC,NSIGMA,NLAMDA,NX,NVN,IPCAL,IRCHGE,NMAX
      CHARACTER MENU,ANS,TITLE*60,TERM
      REAL*8 KRD,KRDSTO,KRDN,LMCMIN,LMCTOT
      DIMENSION RETARD(1)
      COMMON/INTEGS/ IPSPEC,NSIGMA,NLAMDA,NX,NVN,IPCAL,IRCHGE,NMAX
      COMMON/IO/ IUNIT1,IUNIT2,IUNIT3
      COMMON/REALS/ SIGMA(1),RHOB,THETA,TCONV,DKA,DKB,DKH,PH,DKOC,FOC,
     *              ADI,XX(1),ALFAL,ALFAT,VN(1),RCHGE(1),DKS,
     *                NSOURC,BAQFR,AM,ALFAZ
      COMMON/BLOCKA/CD(1,1,1),XD(1),GLAMD(1),SD(1),
     1             ZZ(1),GLAM(1)
      COMMON/BLOCKP/CPF(1,1,1),DLFAC(1,1,1)
      COMMON/MEMOUT/SMMIN,SMTOT,LMCMIN,LMCTOT,DF,RHOM,Q
C-----------------------------------------------------------
C     CALL SRCH$$(K$READ,'IPEPAMS',7,1,ITT,ICOD)
C     CALL SRCH$$(K$WRIT,'OPEPAMS',7,2,ITT,ICOD)
C     CALL SRCH$$(K$RDWR,'OTEPAMS',7,3,ITT,ICOD)
C-----------------------------------------------------------
```

```
C..........................................................     CARD TYPE 00007120
      IF(NMAX.EQ.0) NMAX=104                                              00007130
C.....  READ PARAMETER VALUES                                             00007140
C................................................................. CARD T00007150
C                                                                         00007160
      VS = VN(1)                                                          00007170
C                                                                         00007180
      ISPEC=IPSPEC                                                        00007190
      IF(IPSPEC.EQ.1) GO TO 10                                            00007200
C.....  FOR IPSPEC=0, READ IN DIMENSIONLESS VALUES OF                     00007210
C         STANDARD DEVIATION, DECAY CONSTANT AND DISTANCE                 00007220
C-------------------------                                                00007230
C.................................................................. CARD 00007240
      ALFAL=0.5                                                           00007250
      ALFAT=0.5                                                           00007260
      VS=1.                                                               00007270
      DO 12 J=1,NSIGMA                                                    00007280
   12 SIGMA(J)=SD(J)                                                      00007290
      DO 14 J=1,NX                                                        00007300
   14 XX(J)=XD(J)                                                         00007310
      GO TO 20                                                            00007320
   10 CONTINUE                                                            00007330
C.....  FOR IPSPEC=1, READ IN REAL VALUES OF                               00007340
C         STANDARD DEVIATION, DECAY CONSTANT AND DISTANCE                 00007350
C.............................................................. CARD TY00007360
C----------------------------------                                       00007370
      IF(IPCAL.EQ.0) GO TO 129                                            00007380
C.............................................................. "D TY  00007390
      IF(DABS(TCONV).LE.1.D-20) TCONV=1.D0                                00007400
      DO 149 J=1,NLAMDA                                                   00007410
      DKD = DKOC * FOC                                                    00007420
C.............................................................. CARD TY00007430
      POH=14.-PH                                                          00007440
      PH=-PH                                                              00007450
      POH=-POH                                                            00007460
      GLAM1=DKA*(10.**PH)+DKN+DKB*(10.**POH)                              00007470
      GLAM2=10.*DKA*(10.**PH)+DKN                                         00007480
      GLAM1=GLAM1*TCONV                                                   00007490
      GLAM2=GLAM2*TCONV                                                   00007500
      GLAM(J)=(GLAM1*THETA+GLAM2*DKD*RHOB)/(THETA+DKD*RHOB)               00007510
      RETARD(J)=1.+RHOB*DKD/THETA                                         00007520
  149 CONTINUE                                                            00007530
  129 CONTINUE                                                            00007540
   22 FORMAT(//10X,'BULK DENSITY =',E12.4,8X,'WATER CONTENT =',E12.4,    00007550
     1  8X,'TIME CONVERSION FACTOR =',E12.4//10X,                         00007560
     2  'LIST OF CHEMICAL PROPERTIES OF SOLUTE SPECIES'//                 00007570
     3  5X,'SPECIES#',7X,'CONSTANT KA ',5X,'CONSTANT KB ',5X,             00007580
     4  'CONSTANT KN',5X,'  PH-VALUE   ',3X,'CONST. GLAM1',               00007590
     5  3X,'CONST. GLAM2'/)                                               00007600
   27 FORMAT(1X,I5,8X,6(E14.4,3X))                                        00007610
   54 FORMAT(//10X,'LIST OF RETARDATION VALUES'/)                         00007620
C----------------------------------                                       00007630
      IF(NZ.EQ.0) NZ=1                                                    00007640
C.....  FOR IPSPEC = 1, READ IN VALUES OF LONGITUDINAL AND TRANSVERSE      00007650
C         DISPERSIVITIES, WATER  VELOCITY, AND RECHARGE PARAMETER INDEX   00007660
C.............................................................. CARD TY00007670
C----------------------------                                             00007680
      IF(ALFAZ.LE.1.D-10) ALFAZ=ALFAT                                     00007690
      IF(BAQFR.LE.1.D-10) BAQFR=1.                                        00007700
      IF(HSOURC.LE.1.D-10) HSOURC=1.                                      00007710
      HONB=HSOURC/BAQFR                                                   00007720
      DO 101 J=1,HSIGMA
  101 SD(J)=SIGMA(J)
      DO 102 J=1,HLAMDA
  102 GLAMD(J)=GLAM(J)
      DO 104 J=1,NX
  104 XD(J)=XX(J)
      IF(IRCHGE.EQ.0) GO TO 49
   48 CONTINUE
C..............................................................  CARD
      DO 69 J=1,HLAMDA
      RFAC=1./(THETA*RETARD(J))
   69 GLAM(J)=GLAM(J)+RCHGE(J)*RFAC
   49 CONTINUE
 1032 FORMAT(/10X,'SOLUTE VELOCITY    =',E12.3)
 1034 FORMAT(/10X,'GROUNDWATER SEEPAGE VELOCITY  =',E12.3)
  103 FORMAT(//10X,' LONGITUDINAL DISPERSIVITY =',E12.3//
     1          10X,' TRANSVERSE DISPERSIVITY   =',E12.3//
     1          10X,' VERTICAL DISPERSIVITY     =',E12.3//
     1          10X,' AQUIFER THICKNESS         =',E12.3//
     1          10X,' SOURCE THICKNESS          =',E12.3//
     1          10X,' PENETRATION RATIO         =',E12.3/)
   20 CONTINUE
C...........
C-------------------
      IPRCHK=1
C--------------------
      DO 40 ISIG=1,HSIGMA
      S=SIGMA(ISIG)
C
      DO 38 ILAM=1,HLAMDA
C
      J=ILAM
      IF(ISPEC.EQ.0) RETARD(J)=1.
      IF(ISPEC.EQ.1) KRD=GLAM(ILAM)
      VX=VS/RETARD(J)
      DX=ALFAL*VX
      DY=ALFAT*VX
      DZ=ALFAZ*VX
      DO 36 IX=1,NX
      XP=XX(IX)
      IF(ISPEC.NE.1) KRD=GLAMD(ILAM)/XP
      KRDSTO=KRD
C.....  FULL PENERATION EVALUATION
      DELCCP=0.
      CALL GWP2D0(XP,S,DX,DY,VX,KRD,CCF)
      IF(DABS(CCF).LT.1.D-20) CCF=1.D-20
C.....  PARTIAL PENETRATION EFFECT
      DO 254 IZ=1,NZ
      ZP=ZZ(IZ)
      IF(XP.LE.0.01) GO TO 409
      IF(HONB.LT.0.9900) CALL GWP3DP(XP,ZP,S,DX,DY,DZ,VX,KRDSTO,
     1  BAQFR,HONB,DELCCP,NKEEP)
      CD(IX,ILAM,ISIG)=CCF*HONB+DELCCP
      DLFAC(IX,ILAM,ISIG)=HONB+DELCCP/CCF
      CPF(IX,ILAM,ISIG)=CCF
      GO TO 45
  409 CONTINUE
      NKEEP=0
      CCF=1.0
      CD(IX,ILAM,ISIG)=1.
      DLFAC(IX,ILAM,ISIG)=1.
      CPF(IX,ILAM,ISIG)=1.
      IF(ZP.LT.HSOURC) GO TO 45
      DLFAC(IX,ILAM,ISIG)=0.
      CPF(IX,ILAM,ISIG)=0.
   45 CONTINUE
C
C code added 10/07/88 by R. Moon
C
      SMMIN = (Q * AM * 70.0D0 * ADI * 10.0D-04) / CD(IX,ILAM,ISIG)
      TAU = (XX(1) * ( 1.0D0 + ( DKOC * FOC * RHOB ) / THETA ))
     x        / VH(1)
      SMTOT = (Q * AM * TAU * ADI * 10.0D-04) / CD(IX,ILAM,ISIG)
      LMCMIN = (Q * 70.0D0 * ADI) / (CD(IX,ILAM,ISIG) * DF * RHON)
      LMCTOT = (Q * TAU * ADI) / (CD(IX,ILAM,ISIG) * DF * RHON)
C
      IF(IPRCHK.NE.0) WRITE(1,4993)CD(IX,ILAM,ISIG),
     x                   LMCMIN
4993  FORMAT (F10.7,1X,G11.5)
903     FORMAT(//10X,'PRINT CHECK:XP-ZP-DX-DY-DZ-KRD-CD-CPF-DLFAC',
     1 '- NKEEP'/)
 1093 FORMAT(1X,114('-'))
  993 FORMAT(9E12.4,I7)
  254 CONTINUE
   36 CONTINUE
   30 CONTINUE
   40 CONTINUE
      CALL OUTPUT
  100 CONTINUE
C-----   FORMATS
    1 FORMAT(16I5)
   11 FORMAT(20A4)
   29 FORMAT(3E10.3,I5,3E10.3)
    3 FORMAT(//10X,'NUMBER OF PROBLEMS TO BE SOLVED  =',I5//)
   13 FORMAT(///10X,'PROBLEM NUMBER =',I5//
     1  10X,'NUMBER OF GAUSS POINTS FOR NUMERICAL INTEGRATION =',I5/)
   23 FORMAT(/10X,'PARAMETER SPECIFICATION INDEX =',I5//10X,
     1 'NUMBER OF STANDARD DEVIATION VALUES =',I5//10X,
     2 'NUMBER OF DECAY COEFFICIENT VALUES  =',I5//10X,
     3 'NUMBER OF X-COORDINATE VALUES       =',I5//10X,
     4 'NUMBER OF Z-COORDINATE VALUES       =',I5)
   21 FORMAT(8E10.3)
   33 FORMAT(//10X,'LIST OF STANDARD DEVIATION PARAMETER VALUES'/)
   43 FORMAT(8E12.3)
   53 FORMAT(//10X,'LIST OF DECAY PARAMETER VALUES'/)
   63 FORMAT(//10X,'LIST OF DISTANCE PARAMETER VALUES'/)
C-----------------------------------------------------------
      RETURN
      END

      SUBROUTINE OUTPUT
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 IUNIT1,IUNIT2,IUNIT3,
     x        IPSPEC,NSIGMA,NLAMDA,NX,NVN,IPCAL,IRCHGE,NMAX
      CHARACTER MENU,ANS,TITLE*60,TERM
      REAL*8 KRD,KRDSTO,KRDM,LMCMIN,LMCTOT
      DIMENSION RETARD(1)
      COMMON/INTEGS/ IPSPEC,NSIGMA,NLAMDA,NX,NVN,IPCAL,IRCHGE,NMAX
      COMMON/IO/ IUNIT1,IUNIT2,IUNIT3
      COMMON/REALS/ SIGMA(1),RHOB,THETA,TCONV,DKA,DKB,DKN,PN,DKOC,FOC,
     x          ADI,XX(1),[illegible],VH(1),[illegible],
     x            HSOURC,GAMMA,AM,ALFAZ
```

```
      COMMON/BLOCKA/CD(1,1,1),XD(1),GLAMD(1),SD(1),
     1              ZZ(1),GLAM(1)
      COMMON/BLOCKP/CPF(1,1,1),DLFAC(1,1,1)
      COMMON/NEWOUT/SMMIN,SMTOT,LMCMIN,LMCTOT,DF,RHOM,Q
      NCOL=5
      ITABL=0
      DO 10 ISIG=1,NSIGMA
      SIGD=SD(ISIG)
      ILST=1
      ILEND=ILST+NCOL-1
      IF(ILEND.GT.NLAMDA) ILEND=NLAMDA
   14 CONTINUE
      ITABL=ITABL+1
      IF(IPSPEC.EQ.0) GO TO 19
  133 FORMAT(/12X,5('RCHGE=',E10.3,1X))
      GO TO 69
   19 CONTINUE
   69 CONTINUE
      DO 16 IX=1,NX
      IF(CD(IX,ILST,ISIG).LT.1.E-7) GO TO 16
   16 CONTINUE
  123 FORMAT(2X,93('-')///)
   39 FORMAT(///2X,'TABLE',I3,':',2X,'X VERSUS CD FOR SIGMA =',
     1 E11.3//2X,93('-'))
   49 FORMAT(/12X,5('LAMDA=',E10.3,1X))
   59 FORMAT(3X,'X-VALUE',6X,'CD-VALUE',
     1  4(8X,'CD-VALUE')//2X,93('-')/)
      ILST=ILEND+1
      ILEND=ILST+NCOL-1
      IF(ILST.GT.NLAMDA) GO TO 18
      IF(ILEND.GT.NLAMDA) ILEND=NLAMDA
      GO TO 14
   18 CONTINUE
   10 CONTINUE
C-----  FORMATS
    3 FORMAT(///2X,'TABLE',I3,':',2X,'XD VERSUS CD FOR SIGD =',
     1 E11.3//2X,93('-'))
   13 FORMAT(/12X,5('LAMD=',E10.3,2X))
  113 FORMAT(3X,'XD-VALUE',6X,'CD-VALUE',4(8X,'CD-VALUE')//2X,93('-')/)
   23 FORMAT(1X,E10.3,5(4X,E11.3))
      RETURN
      END

      SUBROUTINE GMP2D0(X,S,DX,DY,VX,KRD,CCP)
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 IUNIT1,IUNIT2,IUNIT5,
     +          IPSPEC,NSIGMA,NLAMDA,NX,NVW,IPCAL,IRCHGE,NMAX
      REAL*8 KRD,KRDSTO,KRDM
      COMMON/IO/ IUNIT1,IUNIT2,IUNIT5
      COMMON/INTEGS/ IPSPEC,NSIGMA,NLAMDA,NX,NVW,IPCAL,IRCHGE,NMAX
      DIMENSION Z(256),H(256)
      TLRNCE=1.D-06
   20 FORMAT(////50X,'ERROR IN SUBROUTINE GMP2D0'//20X,
     1 'THE PARAMETERS DX,DY,S MUST ALL BE GREATER THAN ZERO BUT YOU',
     2 ' SET'///40X,' DX =',E12.4,20X,'DY =',E12.4/
     3 21X,'S = ',E12.4//)
      IF(DX.LE.0..OR.DY.LE.0..OR.S.LE.0.) STOP
      PI=3.14159265358979D0
      CCP=1.D0
      IF(X.LE.TLRNCE) RETURN
      ALPHA=VX*VX/(4.D0*DX)+KRD
      A=0.D0                                                            00009560
      B=1.D+20                                                          00009570
      CALL DGAUSS(A,B,Z,H)                                              00009580
      SUM=0.D0                                                          00009590
      EX0=VX*X/(2.D0*DX)                                                00009600
      DO 100 I=1,NMAX                                                   00009610
      Z2=Z(I)*Z(I)                                                      00009620
C     ACCELERATE THE INTEGRATION BY LETTING Y=Z*Z*DSQRT(2)/S            00009630
      Z4=Z2*Z2                                                          00009640
      EX=EX0-Z4-X*DSQRT(2.D0*DY*Z4/(DX*S*S)+ALPHA/DX)                   00009650
      TERM=0.D0                                                         00009660
      IF(EX.GT.-72.) TERM = Z(I)*H(I)*DEXP(EX)                          00009670
  100 SUM=SUM+TERM                                                      00009680
      CCP=4.D0*SUM/DSQRT(PI)                                            00009690
      RETURN                                                            00009700
      END                                                               00009710
                                                                        00009720
                                                                        00009730
                                                                        00009740
      SUBROUTINE GWP3DP(XP,ZP,S,DX,DY,DZ,VX,KRDSTO,BARFR,               00009750
     1 HONB,DELCCP,NKEEP)                                               00009760
      IMPLICIT REAL*8(A-H,O-Z)                                          00009770
      INTEGER*2 IUNIT1,IUNIT2,IUNIT3,                                   00009780
     +          IPSPEC,MSIGMA,HLAMDA,HX,HVH,IPCAL,IRCHGE,NMAX           00009790
      REAL*8 KRD,KRDSTO,KRDH                                            00009800
      COMMON/IO/ IUNIT1,IUNIT2,IUNIT3                                   00009810
      COMMON/INTEGS/ IPSPEC,MSIGMA,HLAMDA,HX,HVH,IPCAL,IRCHGE,NMAX      00009820
      PI=3.14159265358979D0                                             00009830
      NTERM=200                                                         00009840
      ERROR=1.D-4                                                       00009850
      CONST=2./PI                                                       00009860
      DZCONS=DZ*PI*PI/(BARFR*BARFR)                                     00009870
      DELCCP=0.                                                         00009880
      DO 100 N=1,NTERM                                                  00009890
      EN=N                                                              00009900
      ARG=EN*PI*HONB                                                    00009910
      ZPARG=EN*PI*ZP/BARFR                                              00009920
      ATERM=DSIN(ARG)*DCOS(ZPARG)/EN                                    00009930
      KRDH=KRDSTO+EN*EN*DZCONS                                          00009940
      CALL GWP2D0(XP,S,DX,DY,VX,KRDH,DCTERM)                            00009950
      DELCCP=DELCCP+DCTERM*ATERM                                        00009960
      CTOL=ERROR*DABS(DELCCP)                                           00009970
      IF(DABS(DCTERM).LT.CTOL) GO TO 200                                00009980
  100 CONTINUE                                                          00009990
  200 CONTINUE                                                          00010000
      NKEEP=N                                                           00010010
      DELCCP=DELCCP*CONST                                               00010020
      RETURN                                                            00010030
      END                                                               00010040
                                                                        00010050
                                                                        00010060
                                                                        00010070
                                                                        00010080
                                                                        00010090
                                                                        00010100
                                                                        00010110
      SUBROUTINE DGAUSS(A,B,Z,H)                                        00010120
C                                                                       00010130
C         COMPUTE THE FIRST  NMAX  ROOTS AND WEIGHT FACTORS TO THE      00010140
C     GAUSS-LEGENDRE QUADRATURE INTEGRATION SCHEME                      00010150
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```
C       FOR THE SOLUTION OF INTEGRALS OF THE FORM
C
C              INTEGRAL OF  F(Z)*DZ = SUM OF  W(I)*F(Z(I))
C                                           AS  I = 1,... NMAX
C             INTEGRATED FROM  A TO B
C
C
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 IUNIT1,IUNIT2,IUNIT3,
     +         IPSPEC,NSIGMA,NLAMDA,NX,NVM,IFCAL,IRCHGE,NMAX
      DIMENSION W(256),Z(256)
      COMMON/IO/ IUNIT1,IUNIT2,IUNIT3
      COMMON/INTEGS/ IPSPEC,NSIGMA,NLAMDA,NX,NVM,IFCAL,IRCHGE,NMAX
C
C        A          LOWER LIMIT OF INTEGRATION
C
C        B          UPPER LIMIT OF INTEGRATION
C
C        Z          ROOTS OF THE LEGENDRE POLYNOMIALS P(N+1)(Z)
C
C        W          WEIGHT FACTORS FOR THE GAUSS-LEGENDRE QUADRATURE
C
C       NMAX        NUMBER OF INTEGRATION POINTS
C     NMAX CAN ONLY HAVE THE VALUE OF EITHER 4,5,6,10,15,20,60,104,256
C
C
C
C
C     THE ROOTS AND WEIGHT FACTORS FOR THE NORMALIZED INTEGRAL ARE TAKEN
C     FROM :
C        APPLIED NUMERICAL METHODS
C        BY : B. CARNAHAN, H.A. LUTHER AND J.O. WILKES
C             JOHN WILEY AND SONS, INC.    , 1969
C      AND IN ADDITION :
C              GAUSSIAN QUADRATURE FORMULAS
C      BY : A.H. STROUD AND DON SECREST
C        PRINTICE-HALL, INC.    1966
C
C
C
C        PROGRAMME WAS WRITTEN BY :  MICHAEL J. WONG  JULY, 1976
C
C
C             CHECK IF  A > B
C-----------------------------------------------------
      IF(B.LT.A) WRITE(2,1) A,B,NMAX
 1    FORMAT(//////////,50X,'*****  ERROR IN SUBROUTINE DGAUSS *****',///
     2 ,40X,'THE FOLLOWING VALUES WHERE SPECIFIED',//,30X,'LOWER LIMIT O
     3F INTEGRATION   A = ',D20.12,/,30X,'UPPER LIMIT OF INTEGRATION
     4 = ',D20.12,/,17X,'NUMBER OF GAUSSIAN INTEGRATION POINTS  NMAX = '
     5, I5,//,35X,'YOU VIOLATED THE CONDITION THAT LIMIT B MUST BE GREAT
     6ER OR EQUAL THEN LIMIT  A',//,30X,'PROGRAM SHALL STOP AFTER FORMAT
     7 1  IN SUBROUTINE  DGAUSS')
      IF(B.LT.A) STOP
C
C             NORMALIZED ROOTS AND WEIGHTS
C
      IF(NMAX.NE.4) GO TO 50
[illegible]
[illegible]
[illegible]
```

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      W(3)=.3478548451374538D0                                          00010780
      GO TO 10000                                                       00010790
50    IF(NMAX.NE.5) GO TO 60                                            00010800
      Z(1)=0.                                                           00010810
      Z(2)=.5384693101056830D0                                          00010820
      Z(4)=.9061798459386639D0                                          00010830
      W(1)=.5688888888888888D0                                          00010840
      W(2)=.4786286704993664D0                                          00010850
      W(4)=.2369268850561890D0                                          00010860
      GO TO 10000                                                       00010870
60    IF(NMAX.NE.6) GO TO 100                                           00010880
      Z(1)=.2386191860831969D0                                          00010890
      Z(3)=.6612093864662645D0                                          00010900
      Z(5)=.9324695142031520D0                                          00010910
      W(1)=.4679139345726910D0                                          00010920
      W(3)=.3607615730481386D0                                          00010930
      W(5)=.1713244923791703D0                                          00010940
      GO TO 10000                                                       00010950
100   IF(NMAX.NE.10) GO TO 150                                          00010960
      Z(1)=.148874338981631D0                                           00010970
      Z(3)=.433395394129247D0                                           00010980
      Z(5)=.679409568299024D0                                           00010990
      Z(7)=.865063366688985D0                                           00011000
      Z(9)=.973906528517172D0                                           00011010
      W(1)=.295524224714753D0                                           00011020
      W(3)=.269266719309996D0                                           00011030
      W(5)=.219086362515982D0                                           00011040
      W(7)=.149451349150581D0                                           00011050
      W(9)=.066671344308688D0                                           00011060
      GO TO 10000                                                       00011070
150     IF(NMAX.NE.15) GO TO 200                                        00011080
      Z(1)=0.                                                           00011090
      Z(2)=.201194093997435D0                                           00011100
      Z(4)=.394151347077563D0                                           00011110
      Z(6)=.570972172608539D0                                           00011120
      Z(8)=.724417731360170D0                                           00011130
      Z(10)=.848206583410427D0                                          00011140
      Z(12)=.937273392400706D0                                          00011150
      Z(14)=.987992518020485D0                                          00011160
      W(1)=.202578241925561D0                                           00011170
      W(2)=.198431485327111D0                                           00011180
      W(4)=.186161000015562D0                                           00011190
      W(6)=.166269205816994D0                                           00011200
       W(8)=.139570677926154D0                                          00011210
      W(10)=.107159220467172D0                                          00011220
      W(12)=.070366047488108D0                                          00011230
      W(14)= .030753241996117D0                                         00011240
      GO TO 10000                                                       00011250
200    IF(NMAX.NE.20) GO TO 600                                         00011260
      Z(1)=.7652652113349733D-01                                        00011270
      Z(3)=.2277858511416450D0                                          00011280
      Z(5)=.3737060887154195D0                                          00011290
      Z(7)=.5108670019508270D0                                          00011300
      Z(9)=.6360536807265150D0                                          00011310
      Z(11)=.7463319064601507D0                                         00011320
      Z(13)=.8391169718222188D0                                         00011330
      Z(15)=.9122344282513259D0                                         00011340
      Z(17)= .9639719272779137D0                                        00011350
      Z(19)=[illegible]                                                 00011360
      W(1)=.[illegible]                                                 00011370
      W(3)=.[illegible]                                                 00011380
      H(5)=.14209610931838200D                                    00011390
      H(7)=.13160063844917660D                                    00011400
      H(9)=.11819453196151840D                                    00011410
      H(11)=.10193011981724840D                                   00011420
      H(13)=.83276741576704740D-01                                00011430
      H(15)=.62672048334109060D-01                                00011440
      H(17)=.40601429800386940D-01                                00011450
      H(19)=.17614007139152110D-01                                00011460
      GO TO 10000                                                 00011470
  600  IF(NMAX.NE.60) GO TO 1040                                  00011480
      Z(1)=.25959772301247790D-01                                 00011490
      Z(3)=.77809333949536560D-01                                 00011500
      Z(5)=.12944913539694500D                                    00011510
      Z(7)=.18073996487342540D                                    00011520
      Z(9)=.23154355137602930D                                    00011530
      Z(11)=.28172293742326160D                                   00011540
      Z(13)=.33114284826844810D                                   00011550
      Z(15)=.37967005657679790D                                   00011560
      Z(17)=.42717374158307830D                                   00011570
      Z(19)=.47352584176170710D                                   00011580
      Z(21)=.51860140005856970D                                   00011590
      Z(23)=.56227890075394450D                                   00011600
      Z(25)=.60444059704851030D                                   00011610
      Z(27)=.64497282848947780D                                   00011620
      Z(29)=.68376632738135540D                                   00011630
      Z(31)=.72071651335573030D                                   00011640
      Z(33)=.75572377530658840D                                   00011650
      Z(35)=.78869373993226400D                                   00011660
      Z(37)=.81953752616214570D                                   00011670
      Z(39)=.84817198478592960D                                   00011680
      Z(41)=.87451992264689830D                                   00011690
      Z(43)=.89851031081004590D                                   00011700
      Z(45)=.92007847617762750D                                   00011710
      Z(47)=.93916627611642320D                                   00011720
      Z(49)=.95572225583999610D                                   00011730
      Z(51)=.96970178876505270D                                   00011740
      Z(53)=.98106720175259810D                                   00011750
      Z(55)=.98978789522222170D                                   00011760
      Z(57)=.99584052511883810D                                   00011770
      Z(59)=.99921012322743600D                                   00011780
      H(1)=.51907877631220630D-01                                 00011790
      H(3)=.51767943174910180D-01                                 00011800
      H(5)=.51488451500980930D-01                                 00011810
      H(7)=.51070156069855620D-01                                 00011820
      H(9)=.50514184532509370D-01                                 00011830
      H(11)=.49822035690550180D-01                                00011840
      H(13)=.48995575455756830D-01                                00011850
      H(15)=.48037031819971180D-01                                00011860
      H(17)=.46948980848912280D-01                                00011870
      H(19)=.45734379716114480D-01                                00011880
      H(21)=.44396478795787110D-01                                00011890
      H(23)=.42938892835935640D-01                                00011900
      H(25)=.41365551235584750D-01                                00011910
      H(27)=.39680695452380790D-01                                00011920
      H(29)=.37888867569243440D-01                                00011930
      H(31)=.35994898051084500D-01                                00011940
      H(33)=.34003092724946420D-01                                00011950
      H(35)=.31921219019296320D-01                                00011960
      H(37)=.[illegible]D-01                                      [illegible]
      H(39)=.[illegible]D-01                                      [illegible]
      H(41)=.[illegible]D-01                                      [illegible]
      W(43)=.22769516943997810D-01
      W(45)=.20337120729457280D-01
      W(47)=.17829901014207720D-01
      W(49)=.15274618596784790D-01
      W(51)=.12670166476015960D-01
      W(53)=.10047557182287980D-01
      W(55)=.73899311633454550D-02
      W(57)=.47127299269538460D-02
      W(59)=.20260119688737580D-02
      GO TO 10000
 1040   IF(NMAX.NE.104) GO TO 2840
      Z(1)=.15030805704205800D-01
      Z(3)=.45078833455377860D-01
      Z(5)=.75086122251067031D-01
      Z(7)=.10502555444706640D00
      Z(9)=.13487007296948854D00
      Z(11)=.16459270634967510D00
      Z(13)=.19416659381850810D00
      Z(15)=.22356580088272125D00
      Z(17)=.25276138346572090D00
      Z(19)=.28172933217250800D00
      Z(21)=.31044267617922090D00
      Z(23)=.33887544665692380D00
      Z(25)=.36700286680201650D00
      Z(27)=.39479680200531190D00
      Z(29)=.42223496968490360D00
      Z(31)=.44929147468865260D00
      Z(33)=.47594194654741390D00
      Z(35)=.50216229745345020D00
      Z(37)=.52792883473767720D00
      Z(39)=.55321827156203440D00
      Z(41)=.57800775332757740D00
      Z(43)=.60227487725540040D00
      Z(45)=.62599771263251520D00
      Z(47)=.64915402063111850D00
      Z(49)=.67172527368333620D00
      Z(51)=.69368867439393710D00
      Z(53)=.71502517397392570D00
      Z(55)=.73571549017835850D00
      Z(57)=.75574092473217530D00
      Z(59)=.77508338022830330D00
      Z(61)=.79372537648276850D00
      Z(63)=.81165006633204580D00
      Z(65)=.82884125085838290D00
      Z(67)=.84528339402936260D00
      Z(69)=.86096163473850500D00
      Z(71)=.87586181823427100D00
      Z(73)=.88997044892541100D00
      Z(75)=.90327480255122200D00
      Z(77)=.91576284770591570D00
      Z(79)=.92742329870788640D00
      Z(81)=.93824561779910420D00
      Z(83)=.94822002468348300D00
      Z(85)=.95733750537007330D00
      Z(87)=.96558982034615700D00
      Z(89)=.97296951206735830D00
      Z(91)=.97946991179059190D00
      Z(93)=.98508514880144620D00
      Z(95)=.[illegible]
      Z(97)=.[illegible]
      Z(99)=.[illegible]
      Z(101)=.9986051626519773D0                                        00012610
      Z(103)=.9997382218760882D0                                        00012620
       W(  1) =     .3005934726091462D-01                               00012630
       W(  3) =     .3003218199259360D-01                               00012640
       W(  5) =     .2997787600857805D-01                               00012650
       W(  7) =     .2989647837794739D-01                               00012660
       W(  9) =     .2978806266985645D-01                               00012670
       W( 11) =     .2965272668590822D-01                               00012680
       W( 13) =     .2949059325146727D-01                               00012690
       W( 15) =     .2930180083705914D-01                               00012700
       W( 17) =     .2908654202535895D-01                               00012710
       W( 19) =     .2884499115580069D-01                               00012720
       W( 21) =     .2857737165729427D-01                               00012730
       W( 23) =     .2828392610325431D-01                               00012740
       W( 25) =     .2796491992650960D-01                               00012750
       W( 27) =     .2762064110882044D-01                               00012760
       W( 29) =     .2725140107556215D-01                               00012770
       W( 31) =     .2685753330333987D-01                               00012780
       W( 33) =     .2643939381002818D-01                               00012790
       W( 35) =     .2599736047717819D-01                               00012800
       W( 37) =     .2553183277970497D-01                               00012810
       W( 39) =     .2504323142490426D-01                               00012820
       W( 41) =     .2453199797222264D-01                               00012830
       W( 43) =     .2399859443422820D-01                               00012840
       W( 45) =     .2344350265908804D-01                               00012850
       W( 47) =     .2286722489409493D-01                               00012860
       W( 49) =     .2227026133640237D-01                               00012870
       W( 51) =     .2165321165429792D-01                               00012880
       W( 53) =     .2101657350772073D-01                               00012890
       W( 55) =     .2036094224029608D-01                               00012900
       W( 57) =     .1968691036020432D-01                               00012910
       W( 59) =     .1899508700473277D-01                               00012920
       W( 61) =     .1828609730982209D-01                               00012930
       W( 63) =     .1756058224580301D-01                               00012940
       W( 65) =     .1681919723481402D-01                               00012950
       W( 67) =     .1606261234555251D-01                               00012960
       W( 69) =     .1529151130069267D-01                               00012970
       W( 71) =     .1450659114276789D-01                               00012980
       W( 73) =     .1370856100396590D-01                               00012990
       W( 75) =     .1289814216558273D-01                               00013000
       W( 77) =     .1207606702671640D-01                               00013010
       W( 79) =     .1124307052416543D-01                               00013020
       W( 81) =     .1039992946259468D-01                               00013030
       W( 83) =     .9547301836326911D-02                               00013040
       W( 85) =     .8686206157923711D-02                               00013050
       W( 87) =     .7817100756425343D-02                               00013060
       W( 89) =     .6941091125100978D-02                               00013070
       W( 91) =     .6058729274750651D-02                               00013080
       W( 93) =     .5170893207327758D-02                               00013090
       W( 95) =     .4278306752472274D-02                               00013100
       W( 97) =     .3382082001060703D-02                               00013110
       W( 99) =     .2482621002176784D-02                               00013120
       W(101) =     .1581095291194842D-02                               00013130
       W(103) =     .6794761824048829D-03                               00013140
      GO TO 10000                                                       00013150
 2560   IF(NMAX.NE.256) GO TO 3000                                      00013160
      Z(1)=.6123912375109529D-02                                        00013170
      Z(3)=.1837081047801366D-01                                        00013180
      Z(5)=.[illegible]D-01                                             [illegible]
      Z(7)=.[illegible]D-01                                             [illegible]
      Z(9)=.[illegible]D-01                                             [illegible]
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Z(11)=.6731252116871640D-01                              00013220
Z(13)=.7952728910023296D-01                              00013230
Z(15)=.9173012716351955D-01                              00013240
Z(17)=.1039192048105094D00                               00013250
Z(19)=.1160926935603320D00                               00013260
Z(21)=.1282487672706070D00                               00013270
Z(23)=.1403856024113750D00                               00013280
Z(25)=.1525013783386563D00                               00013290
Z(27)=.1645942775675530D00                               00013300
Z(29)=.1766624860449019D00                               00013310
Z(31)=.1887041934213000D00                               00013320
Z(33)=.2007175933231264D00                               00013330
Z(35)=.2127080836226259D00                               00013340
Z(37)=.2246522667091319D00                               00013350
Z(39)=.2365699497502840D00                               00013360
Z(41)=.2484521458010564D00                               00013370
Z(43)=.2602970699919425D00                               00013380
Z(45)=.2721029478763366D00                               00013390
Z(47)=.2838600076578817D00                               00013400
Z(49)=.2955990484601386D00                               00013410
Z(51)=.3072686197993198D00                               00013420
Z(53)=.3189086618401062D00                               00013430
Z(55)=.3304868656624169D00                               00013440
Z(57)=.3420194935223716D00                               00013450
Z(59)=.3535028151129697D00                               00013460
Z(61)=.3649331078236540D00                               00013470
Z(63)=.3763084569987163D00                               00013480
Z(65)=.3876277861945158D00                               00013490
Z(67)=.3988807074384591D00                               00013500
Z(69)=.4100096214487165D00                               00013510
Z(71)=.4212294180176238D00                               00013520
Z(73)=.4323050260337413D00                               00013530
Z(75)=.4433173839475273D00                               00013540
Z(77)=.4542624399175899D00                               00013550
Z(79)=.4651393520784793D00                               00013560
Z(81)=.4759464087069833D00                               00013570
Z(83)=.4866822268668993D00                               00013580
Z(85)=.4973449610521014D00                               00013590
Z(87)=.5079330082286160D00                               00013600
Z(89)=.5184450196736744D00                               00013610
Z(91)=.5288791792946222D00                               00013620
Z(93)=.5392348001866891D00                               00013630
Z(95)=.5495079340662718D00                               00013640
Z(97)=.5596994346944811D00                               00013650
Z(99)=.5698069749365487D00                               00013660
Z(101)=.5798290385590829D00                              00013670
Z(103)=.5897641221844543D00                              00013680
Z(105)=.5996107335629683D00                              00013690
Z(107)=.6093674010963339D00                              00013700
Z(109)=.6190326557592612D00                              00013710
Z(111)=.6286050494690149D00                              00013720
Z(113)=.6380831462729113D00                              00013730
Z(115)=.6474655243637240D00                              00013740
Z(117)=.6567507762929732D00                              00013750
Z(119)=.6659375091820448D00                              00013760
Z(121)=.6750243449311627D00                              00013770
Z(123)=.6840099204260759D00                              00013780
Z(125)=.6928928077425769D00                              00013790
Z(127)=.7016712143[illegible]                            0001[illegible]
Z(129)=.[illegible]                                      0001[illegible]
Z(131)=.71[illegible]                                    0001[illegible]
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Z(133)=.7273722596496521D0                                    00013830
Z(135)=.7357222512085917D0                                    00013840
Z(137)=.7439624008491115D0                                    00013850
Z(139)=.7520906065754920D0                                    00013860
Z(141)=.7601061516426554D0                                    00013870
Z(143)=.7680075933824454D0                                    00013880
Z(145)=.7757930264113257D0                                    00013890
Z(147)=.7834636820081830D0                                    00013900
Z(149)=.7910160119095459D0                                    00013910
Z(151)=.7984496810321797D0                                    00013920
Z(153)=.8057635748129986D0                                    00013930
Z(155)=.8129565961764315D0                                    00013940
Z(157)=.8200276646098917D0                                    00013950
Z(159)=.8269757238508125D0                                    00013960
Z(161)=.8337997271555048D0                                    00013970
Z(163)=.8404906523457627D0                                    00013980
Z(165)=.8470714945172962D0                                    00013990
Z(167)=.8535172676795029D0                                    00014000
Z(169)=.8598350049033763D0                                    00014010
Z(171)=.8660237584665545D0                                    00014020
Z(173)=.8720825999954882D0                                    00014030
Z(175)=.8780106206047865D0                                    00014040
Z(177)=.8838069310331582D0                                    00014050
Z(179)=.8894706617776108D0                                    00014060
Z(181)=.8950009632230845D0                                    00014070
Z(183)=.9003970857703835D0                                    00014080
Z(185)=.9056579799601446D0                                    00014090
Z(187)=.9107830965950650D0                                    00014100
Z(189)=.9157715868574983D0                                    00014110
Z(191)=.9206227024251464D0                                    00014120
Z(193)=.9253357158833162D0                                    00014130
Z(195)=.9299099193340856D0                                    00014140
Z(197)=.9343444627802083D0                                    00014150
Z(199)=.9386391748378148D0                                    00014160
Z(201)=.9427929171117462D0                                    00014170
Z(203)=.9468052312391274D0                                    00014180
Z(205)=.9506755153166282D0                                    00014190
Z(207)=.9544031887697162D0                                    00014200
Z(209)=.9579876924111781D0                                    00014210
Z(211)=.9614204888307321D0                                    00014220
Z(213)=.9647258689757064D0                                    00014230
Z(215)=.9678769182284894D0                                    00014240
Z(217)=.9708835784887430D0                                    00014250
Z(219)=.9737445997843784D0                                    00014260
Z(221)=.9764595497192341D0                                    00014270
Z(223)=.9790280212576222D0                                    00014280
Z(225)=.9814496298254444D0                                    00014290
Z(227)=.9837240097603154D0                                    00014300
Z(229)=.9858508222061259D0                                    00014310
Z(231)=.9878297475648606D0                                    00014320
Z(233)=.9896604887450652D0                                    00014330
Z(235)=.9913427712875830D0                                    00014340
Z(237)=.9928763426888221D0                                    00014350
Z(239)=.9942609729224896D0                                    00014360
Z(241)=.9954964544810963D0                                    00014370
Z(243)=.9965826028233815D0                                    00014380
Z(245)=.9975192527567288D0                                    00014390
Z(247)=.99830626[illegible]73894D0                                    00014400
Z(249)=.[illegible]                                    00014410
Z(251)=.[illegible]                                    00014420
Z(253)=.[illegible]                                    00014430
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Z(255)=.9999560500189922D00                           00014440
W(1)=.1224767164028975D-01                            00014450
W(3)=.1224503436974792D-01                            00014460
W(5)=.1224216010427280D-01                            00014470
W(7)=.1223664939504015D-01                            00014480
W(9)=.1222930386871027D-01                            00014490
W(11)=.1222012222730396D-01                           00014500
W(13)=.1220910824803724D-01                           00014510
W(15)=.1219626278311471D-01                           00014520
W(17)=.1218158677594017D-01                           00014530
W(19)=.1216508537853558D-01                           00014540
W(21)=.1214675811579445D-01                           00014550
W(23)=.1212660872852732D-01                           00014560
W(25)=.1210464021534044D-01                           00014570
W(27)=.1208085589672494D-01                           00014580
W(29)=.1205525932956014D-01                           00014590
W(31)=.1202785435650257D-01                           00014600
W(33)=.1199864508788581D-01                           00014610
W(35)=.1196763598498589D-01                           00014620
W(37)=.1193483148956386D-01                           00014630
W(39)=.1190023667276448D-01                           00014640
W(41)=.1186385673407107D-01                           00014650
W(43)=.1182569710082397D-01                           00014660
W(45)=.1178576349734342D-01                           00014670
W(47)=.1174406191406855D-01                           00014680
W(49)=.1170059860662074D-01                           00014690
W(51)=.1165538009494524D-01                           00014700
W(53)=.1160841316225310D-01                           00014710
W(55)=.1155970485404363D-01                           00014720
W(57)=.1150926247703949D-01                           00014730
W(59)=.1145709359809862D-01                           00014740
W(61)=.1140320604303918D-01                           00014750
W(63)=.1134760789554549D-01                           00014760
W(65)=.1129030749587550D-01                           00014770
W(67)=.1123131343964966D-01                           00014780
W(69)=.1117063457655344D-01                           00014790
W(71)=.1110828000900984D-01                           00014800
W(73)=.1104425909081398D-01                           00014810
W(75)=.1097858142572957D-01                           00014820
W(77)=.1091125686604983D-01                           00014830
W(79)=.1084229551111479D-01                           00014840
W(81)=.1077170770580462D-01                           00014850
W(83)=.1069950403897978D-01                           00014860
W(85)=.1062569534189656D-01                           00014870
W(87)=.1055029260658148D-01                           00014880
W(89)=.1047330730417048D-01                           00014890
W(91)=.1039475098321172D-01                           00014900
W(93)=.1031463526793401D-01                           00014910
W(95)=.1023297225647021D-01                           00014920
W(97)=.1014977419909406D-01                           00014930
W(99)=.1006505387630630D-01                           00014940
W(101)=.9970023097034918D-02                          00014950
W(103)=.9891095696695828D-02                          00014960
W(105)=.9801804535257327D-02                          00014970
W(107)=.9711202995266279D-02                          00014980
W(109)=.9619064679840727D-02                          00014990
W(111)=.9525483410629204D-02                          00015000
W(113)=.9430473225737752D-02                          00015010
W(115)=[illegible]                                    00015020
W(117)=[illegible]                                    [illegible]
W(119)=[illegible]                                    00015040
```

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H(121)=.9036431548662873D-02                                    00015050
H(123)=.8934494783758207D-02                                    00015060
H(125)=.8831217757248750D-02                                    00015070
H(127)=.8726615961696807D-02                                    00015080
H(129)=.8620705088401014D-02                                    00015090
H(131)=.8513501025022490D-02                                    00015100
H(133)=.8405019853221535D-02                                    00015110
H(135)=.8295277846235225D-02                                    00015120
H(137)=.8184291466438269D-02                                    00015130
H(139)=.8072077362873499D-02                                    00015140
H(141)=.7958652368784340D-02                                    00015150
H(143)=.7844033498939711D-02                                    00015160
H(145)=.7728237947381555D-02                                    00015170
H(147)=.7611203884548659D-02                                    00015180
H(149)=.7493186485488583D-02                                    00015190
H(151)=.7373965773812346D-02                                    00015200
H(153)=.7253638925833913D-02                                    00015210
H(155)=.7132223961075390D-02                                    00015220
H(157)=.7009739092969822D-02                                    00015230
H(159)=.6886202695446320D-02                                    00015240
H(161)=.6761633300173798D-02                                    00015250
H(163)=.6636049593781065D-02                                    00015260
H(165)=.6509478415053660D-02                                    00015270
H(167)=.6381914752107080D-02                                    00015280
H(169)=.6253401739542401D-02                                    00015290
H(171)=.6123950655567932D-02                                    00015300
H(173)=.5993580919115338D-02                                    00015310
H(175)=.5862312086922653D-02                                    00015320
H(177)=.5730163850601437D-02                                    00015330
H(179)=.5597156033682918D-02                                    00015340
H(181)=.5463308880644310D-02                                    00015350
H(183)=.5328641593915930D-02                                    00015360
H(185)=.5193175250869288D-02                                    00015370
H(187)=.5056929888786042D-02                                    00015380
H(189)=.4919925921813865D-02                                    00015390
H(191)=.4782183925892691D-02                                    00015400
H(193)=.4643724555688060D-02                                    00015410
H(195)=.4504568581447897D-02                                    00015420
H(197)=.4364736877968056D-02                                    00015430
H(199)=.4224258421301534D-02                                    00015440
H(201)=.4083130286052668D-02                                    00015450
H(203)=.3941397641486833D-02                                    00015460
H(205)=.3799073748766257D-02                                    00015470
H(207)=.3656179958142582D-02                                    00015480
H(209)=.3512737785056387D-02                                    00015490
H(211)=.3360768587315551D-02                                    00015500
H(213)=.3224293961794190D-02                                    00015510
H(215)=.3079335741199337D-02                                    00015520
H(217)=.2933915590829716D-02                                    00015530
H(219)=.2788055325327706D-02                                    00015540
H(221)=.2641776825427498D-02                                    00015550
H(223)=.2495102034703706D-02                                    00015560
H(225)=.2348052956327312D-02                                    00015570
H(227)=.2200651649839910D-02                                    00015580
H(229)=.2052920227966143D-02                                    00015590
H(231)=.1904600853499710D-02                                    00015600
H(233)=.1756555736330729D-02                                    00015610
H(235)=.1607967130749327D-02                                    00015620
H(237)=.1459137233310733D-02                                    00015630
H(239)=.13[illegible]D-02                                    000156[illegible]
H(241)=.116[illegible]D-02                                    000156[illegible]
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```
      W(243)=.1011424393208440D-02
      W(245)=.8618537014200890D-03
      W(247)=.7121541634733206D-03
      W(249)=.5623489540314098D-03
      W(251)=.4124632544261763D-03
      W(253)=.2625349442964459D-03
      W(255)=.1127090178222721D-03
      GO TO 10000
 3000  CONTINUE
      WRITE(2,4000)NMAX
 4000 FORMAT(/////,40X,'*****  ERROR FLAG FROM SUBROUTINE DGAUSS *****',
     2//,20X,'SUBROUTINE  DGAUSS  DOES NOT CONTAIN THE  NMAX= ', I3,
     $' ROOTS AND WEIGHT FACTORS',
     3                  /, 20X,'FOR THE GAUSS-LEGENDRE QUADRADURE INTE
     4RATION SCHEME, THEY MUST BE ADDED ',/, 30X,'PROGRAM SHALL END AFTE
     5R FORMAT 4000  IN SUBROUTINE  DGAUSS')
      STOP
10000  CONTINUE
C
C             CONSTRUCT THE REMAINING COEFFICIENTS FROM THE GIVEN ONES
C
      N0=0
      NF=NMAX/2
      IF(Z(1).EQ.0.) N0=1
      NJ=N0
      DO 10100 J=1,NF
      NJ=NJ+2
      Z(NJ)=-Z(NJ-1)
10100  W(NJ)=W(NJ-1)
C
C      CHECK IF LOWER AND UPPER INTEGRATION LIMITS ARE FINITE
C     OR INFINITE
      IF(A.LE.-1.D+10) GO TO 30000
      IF(B.GE.1.D+10) GO TO 50000
C
C        ADJUST THE COEFFICIENTS TO ACCOUNT FOR THE NON-NORMALIZED
C     LIMITS OF INTEGRATION
C     WHERE
C        W(I)      WN(I)*(B-A)/2
C
C        Z(I)      (ZN(I)*(B-A)+B+A)/2
C
C                   WHERE WN(I) AND  ZN(I)  ARE THE NORMALIZED
C                      GAUSSIAN WEIGHTS AND ROOTS
C     SEE PAGE 104 AND EQ 2.98 IN THE " APPLIED NUMERICAL METHODS"
C
      DO 20000 I=1,NMAX
      W(I)=W(I)*(B-A)/2.D0
20000  Z(I)=(Z(I)*(B-A)+B+A)/2.D0
      RETURN
30000  CONTINUE
C
C     SPECIAL CASE WHEN  A --> - INFINITY
C
      DO 40000 I=1,NMAX
      W(I)=W(I)/(Z(I)+1.D0)
40000  Z(I)=B+DLOG((Z(I)+1.D0)/2.D0)
C     CHECK IF THIS INTEGRAL HAS INFINITE UPPER AND LOWER LIMITS
C     OF INTEGRATION
      IF(B.GE.1.D+10) GO TO 60000
      RETURN
```

```
50000 CONTINUE
C
C         SPECIAL CASE WHEN  B--> INFINITY
C
      DO 60000 I=1,NMAX
      W(I)=W(I)/(Z(I)+1.D0)
60000 Z(I)=A+DLOG(2.D0/(Z(I)+1.D0))
C     CHECK IF ONE IS TRYING TO SOLVE THE INFINITE INTEGRAL
      IF(A.LE.-1.D+10) GO TO 80000
      RETURN
80000 CONTINUE
      II=0
C
C     IF WE  WANT TO SOLVE A PROBLEM WITH  A--> - INFINITY AND
C     B --> + INFINITY, THEN BREAK THE INTEGRATION INTO TWO
C     SEMI-INFINITE INTEGRALS
C     THUS :  F(X)*DX (-INF,+INF) = F(X)*DX (-INF,0) + F(X)*DX (0,+INF)
C
      WRITE(2,  90000) A,B,NMAX
90000   FORMAT(///////////,30X,'*****  ERROR IN SUBROUTINE  DGAUSS  *****
     2',//, 30X,'DGAUSS WAS CALLED WITH  A = ', D20.12,/, 54X,'B = ',
     3D20.12,/, 51X,' NMAX= ', I3,///,10X,'THIS SUBROUTINE CAN NOT HANDL
     4E AN INTEGRAL WHERE BOTH THE UPPER AND LOWER LIMITS OF INTEGRATION
     5 ARE INFINITE', ///, 20X,'WHAT TO DO ...DEFINE A NEW PROBLEM SUCH
     6THAT',//,20X,  'F(X)*DX (-INF,+INF)  =  F(X)*DX (-INF,0)  +  F(X)*
     7DX (0,+INF)   WHERE  INF = 1.D+20 ',//,20X,'PROGRAM SHALL END AFTE
     8R FORMAT 90000 IN SUBROUTINE DGAUSS')
      IF(II.EQ.0) STOP
      RETURN
      END
```

```
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
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D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
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D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
D032 A  END  TSU 4430 GGE        ACCT CARD  4.03.34 PM  9 DEC 85 L20.SR1  PRINTER2 MSC1  DP     BL     RM D032
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